



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	PATENT NUMBER	GROUP ART UNIT	FILE WRAPPER LOCATION
61/034,116			



Correspondence Address/Fee Address Change

The following fields have been set to Customer Number 14870 on 05/19/2011

- Correspondence Address
- Maintenance Fee Address

The address of record for Customer Number 14870 is:

14870
KNOBBE, MARTENS, OLSON & BEAR, LLP
2040 Main Street
Fourteenth Floor
Irvine, CA 92614



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
61/034,116	03/05/2008	Nigel Cook	092410P1

23696
QUALCOMM INCORPORATED
5775 MOREHOUSE DR.
SAN DIEGO, CA 92121

CONFIRMATION NO. 4622
POA ACCEPTANCE LETTER



OC000000039132373*

Date Mailed: 12/14/2009

NOTICE OF ACCEPTANCE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 12/02/2009.

The Power of Attorney in this application is accepted. Correspondence in this application will be mailed to the above address as provided by 37 CFR 1.33.

/ttkim/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING OR 371(C) DATE	FIRST NAMED APPLICANT	ATTY. DOCKET NO./TITLE
61/034,116	03/05/2008	Nigel Cook	NigelPower-PP21Packaging

CONFIRMATION NO. 4622

74162

Law Office of Scott C Harris Inc
PO Box 1389
Rancho Santa Fe, CA 92067

POWER OF ATTORNEY NOTICE



OC000000039132350

Date Mailed: 12/14/2009

NOTICE REGARDING CHANGE OF POWER OF ATTORNEY

This is in response to the Power of Attorney filed 12/02/2009.

- The Power of Attorney to you in this application has been revoked by the assignee who has intervened as provided by 37 CFR 3.71. Future correspondence will be mailed to the new address of record(37 CFR 1.33).

/tkim/

Office of Data Management, Application Assistance Unit (571) 272-4000, or (571) 272-4200, or 1-888-786-0101

POWER OF ATTORNEY OR REVOCATION OF POWER OF ATTORNEY WITH A NEW POWER OF ATTORNEY AND CHANGE OF CORRESPONDENCE ADDRESS	Application Number	61/034,116
	Filing Date	03/05/2008
	First Named Inventor	Nigel P. Cook
	Title	Packagin of a Wireless Pow...
	Art Unit	unknown
	Examiner Name	unknown
	Attorney Docket Number	092410P1

I hereby revoke all previous powers of attorney given in the above-identified application.

☐ A Power of Attorney is submitted herewith.

OR

☒ I hereby appoint Practitioner(s) associated with the following Customer Number as my/our attorney(s) or agent(s) to prosecute the application identified above, and to transact all business in the United States Patent and Trademark Office connected therewith:

23696

OR

☐ I hereby appoint Practitioner(s) named below as my/our attorney(s) or agent(s) to prosecute the application identified above, and to transact all business in the United States Patent and Trademark Office connected therewith:

Practitioner(s) Name	Registration Number

Please recognize or change the correspondence address for the above-identified application to:

☒ The address associated with the above-mentioned Customer Number.

OR

☐ The address associated with Customer Number:

OR

☐ Firm or Individual Name

Address

City

State

Zip

Country

Telephone

Email

I am the:

☐ Applicant/Inventor.

OR

☒ Assignee of record of the entire interest. See 37 CFR 3.71.

Statement under 37 CFR 3.73(b) (Form PTO/SB/96) submitted herewith or filed on _____

SIGNATURE of Applicant or Assignee of Record

Signature	<i>Charles D. Brown</i>	Date	1-23-09
Name	Charles D. Brown, Reg.No. 28,285	Telephone	858.651.6731
Title and Company	VP Patent Counsel, Qualcomm Incorporated		

NOTE: Signatures of all the inventors or assignees of record of the entire interest or their representative(s) are required. Submit multiple forms if more than one signature is required, see below.

☐ *Total of _____ forms are submitted.

This collection of information is required by 37 CFR 1.31, 1.32 and 1.33. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 3 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it displays a valid OMB control number.

STATEMENT UNDER 37 CFR 3.73(b)Applicant/Patent Owner: Qualcomm IncorporatedApplication No./Patent No.: 61/034,116Filed/Issue Date: 03/05/2008

Titled:

Packaging of a wireless power device

Qualcomm Incorporated, a Corporation

(Name of Assignee)

(Type of Assignee, e.g., corporation, partnership, university, government agency, etc.)

states that it is:

1. ☒ the assignee of the entire right, title, and interest in;
2. ☐ an assignee of less than the entire right, title, and interest in
(The extent (by percentage) of its ownership interest is _____ %); or
3. ☐ the assignee of an undivided interest in the entirety of (a complete assignment from one of the joint inventors was made)

the patent application/patent identified above, by virtue of either:

- A. ☐ An assignment from the inventor(s) of the patent application/patent identified above. The assignment was recorded in the United States Patent and Trademark Office at Reel _____, Frame _____, or for which a copy therefore is attached.

OR

- B. ☒ A chain of title from the inventor(s), of the patent application/patent identified above, to the current assignee as follows:

1. From: Nigel P. Cook et. al.To: Nigel Power LLC

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

2. From: Nigel Power LLCTo: Qualcomm Incorporated

The document was recorded in the United States Patent and Trademark Office at

Reel 023445, Frame 0266, or for which a copy thereof is attached.

3. From: _____

To: _____

The document was recorded in the United States Patent and Trademark Office at

Reel _____, Frame _____, or for which a copy thereof is attached.

☐ Additional documents in the chain of title are listed on a supplemental sheet(s).

- ☒ As required by 37 CFR 3.73(b)(1)(i), the documentary evidence of the chain of title from the original owner to the assignee was, or concurrently is being, submitted for recordation pursuant to 37 CFR 3.11.

[NOTE: A separate copy (i.e., a true copy of the original assignment document(s)) must be submitted to Assignment Division in accordance with 37 CFR Part 3, to record the assignment in the records of the USPTO. See MPEP 302.08]

The undersigned (whose title is supplied below) is authorized to act on behalf of the assignee.

Charles D. Brown

Signature

11-23-09

Date

Charles D. Brown

VP Patent Counsel

Printed or Typed Name

Title

This collection of information is required by 37 CFR 3.73(b). The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.11 and 1.14. This collection is estimated to take 12 minutes to complete, including gathering, preparing, and submitting the completed application form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.

If you need assistance in completing the form, call 1-800-PTO-9199 and select option 2.

ASSIGNMENT

WHEREAS, We, **Nigel P. Cook**, a British citizen, having an address at 1739 Vakas Drive, El Cajon, California 92019, United States, **Lukas Sieber**, a Swiss citizen, having an address at Höhenstrasse- West 23, CH 4600 Olten, Switzerland, and **Hanspeter Widmer**, a Swiss citizen, having an address at Jasminweg 1, CH 5612 Wohlenschwil, Switzerland, have invented certain new and useful improvements in **PACKAGING OF A WIRELESS POWER DEVICE** for which we have filed an application for Letters Patent in the United States, identified as U.S. Application No. 61/034,116, and filed on March 5, 2008;

AND WHEREAS, **Nigel Power LLC** (hereinafter "ASSIGNEE"), a Delaware limited liability company, with its principal place of business at 11512 El Camino Real, Suite 100, San Diego, California, 92130, United States, desires to acquire the entire right, title, and interest in and to the said improvements and the said Application;

NOW, THEREFORE, for good and valuable consideration, the receipt of which is hereby acknowledged, we, the said inventors, do hereby acknowledge that we have sold, assigned, transferred, and set over, and by these presents do hereby sell, assign, transfer and set over, unto the said ASSIGNEE, his successors, legal representatives and assigns, the entire right, title, and interest throughout the world in, to and under the said improvements, and the said application and all non-provisional applications claiming the benefit thereof, and all divisions, renewals and continuations of said non-provisional applications, and all Letters Patent of the United States which may be granted thereon and all reissues and extensions thereof, and all rights of priority under International Conventions and applications for Letters Patent which may hereafter be filed for said improvements in any country or countries foreign to the United States, and all Letters Patent which may be granted for said improvements in any country or countries foreign to the United States and all extensions, renewals, and reissues thereof; and we hereby authorize and request the Commissioner of Patents of the United States, and any Official of any country or countries foreign to the United States, whose duty it is to issue patents on applications as aforesaid, to issue all Letters Patent for said improvements to the said ASSIGNEE, his successors, legal representatives and assigns, in accordance with the terms of this instrument.

AND WE DO HEREBY, sell, assign, transfer, and convey to ASSIGNEE, his successors, legal representatives, and assigns all claims for damages and all remedies arising out of any violation of the rights assigned hereby that may have accrued prior to the date of assignment to ASSIGNEE, or may accrue hereafter, including, but not limited to, the right to sue for, collect, and retain damages for past infringements of the said Letters Patent before or after issuance.

AND WE HEREBY covenant and agree that we will communicate to the said ASSIGNEE, his successors, legal representatives, and assigns, any facts known to us respecting said improvements, and testify in any legal proceeding, sign all lawful papers, execute all divisional, continuing, and reissue applications, make all rightful oaths and generally do everything possible to aid the said ASSIGNEE, his successors, legal representatives, and assigns, to obtain and enforce proper patent protection for said improvements in all countries.

IN TESTIMONY WHEREOF, I hereunto set my hand and seal this 14 day of May, 2009.



Nigel P. Cook

Please attach notarization.

IN TESTIMONY WHEREOF, I hereunto set my hand and seal this ____ day of _____, 2009.

Lukas Sieber

Please attach apostille.

IN TESTIMONY WHEREOF, I hereunto set my hand and seal this ____ day of _____, 2009.

Hanspeter Widmer

Please attach apostille.

ACKNOWLEDGMENT

State of California
County of San Diego ss.

On May 14, 2009 before me, Jenny Nguyen, Notary Public, personally appeared Nigel P. Cook, who proved to me on the basis of satisfactory evidence to be the person whose name is subscribed to the within instrument and acknowledged to me that he executed the same in his authorized capacity, and that by his signatures on the instrument the person, or the entity upon behalf of which the person acted, executed the instrument.

I certify under PENALTY OF PERJURY under the laws of the State of California that the foregoing paragraph is true and correct.

WITNESS my hand and official seal.



Signature _____

(seal)

OPTIONAL INFORMATION

Date of Document _____

Thumbprint of Signer

Type or Title of Document _____

Number of Pages in Document _____

Document in a Foreign Language _____

Type of Satisfactory Evidence:

- ☐ Personally Known with Paper Identification
☐ Paper Identification
☐ Credible Witness(es)

Capacity of Signer:

- ☐ Trustee
☐ Power of Attorney
☐ CEO / CFO / COO
☐ President / Vice-President / Secretary / Treasurer
☐ Other: _____

☐ Check here if
no thumbprint
or fingerprint
is available.

Other Information: _____

IN TESTIMONY WHEREOF, I hereunto set my hand and seal this ____ day of _____, 2009.

Nigel P. Cook

Please attach notarization.

IN TESTIMONY WHEREOF, I hereunto set my hand and seal this 15 day of May, 2009.

L. Sieber
Lukas Sieber

Please attach apostille.

IN TESTIMONY WHEREOF, I hereunto set my hand and seal this 15 day of May, 2009.

Hanspeter Widmer

Please attach apostille.

Max Müller, Notary Public of the Canton of Aargau (= AG), Switzerland,
with office in Lenzburg AG, Switzerland, certifies:

- CH-5600 Lenzburg AG, Switzerland, May 15, 2009
(fifteenth of May, two-thousand-and-nine) /m

in Vertretung:
Manuela Hübner

Electronic Acknowledgement Receipt	
EFS ID:	6561229
Application Number:	61034116
International Application Number:	
Confirmation Number:	4622
Title of Invention:	Packagin of a Wireless Power device
First Named Inventor/Applicant Name:	Nigel Cook
Customer Number:	74162
Filer:	Charles David Brown/Angela Hergenroeder
Filer Authorized By:	Charles David Brown
Attorney Docket Number:	NigelPower-PP21Packaging
Receipt Date:	02-DEC-2009
Filing Date:	05-MAR-2008
Time Stamp:	19:07:26
Application Type:	Provisional

Payment information:

Submitted with Payment		no			
File Listing:					
Document Number	Document Description	File Name	File Size(Bytes)/ Message Digest	Multi Part /.zip	Pages (if appl.)
1		092410P1.pdf	1507116	yes	7
			39e76c3ea9ddb30701f8cd4537916bc628b2afc5		

Multipart Description/PDF files in .zip description			
Document Description		Start	End
Power of Attorney		1	1
Assignee showing of ownership per 37 CFR 3.73(b).		2	7

Warnings:

The page size in the PDF is too large. The pages should be 8.5 x 11 or A4. If this PDF is submitted, the pages will be resized upon entry into the Image File Wrapper and may affect subsequent processing

Information:

Total Files Size (in bytes):	1507116
-------------------------------------	---------

This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503.

New Applications Under 35 U.S.C. 111
If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application.

National Stage of an International Application under 35 U.S.C. 371
If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course.

New International Application Filed with the USPTO as a Receiving Office
If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.



UNITED STATES PATENT AND TRADEMARK OFFICE

UNITED STATES DEPARTMENT OF COMMERCE
United States Patent and Trademark Office
Address: COMMISSIONER FOR PATENTS
P.O. Box 1450
Alexandria, Virginia 22313-1450
www.uspto.gov

APPLICATION NUMBER	FILING or 371(c) DATE	GRP ART UNIT	FIL FEE REC'D	ATTY.DOCKET.NO	TOT CLAIMS	IND CLAIMS
61/034,116	03/05/2008		105	NigelPower-PP21Packaging		

CONFIRMATION NO. 4622

FILING RECEIPT



OC00000028898086

74162

Law Office of Scott C Harris

PO Box 1389

Rancho Santa Fe, CA 92067

Date Mailed: 03/19/2008

Receipt is acknowledged of this provisional patent application. It will not be examined for patentability and will become abandoned not later than twelve months after its filing date. Any correspondence concerning the application must include the following identification information: the U.S. APPLICATION NUMBER, FILING DATE, NAME OF APPLICANT, and TITLE OF INVENTION. Fees transmitted by check or draft are subject to collection. Please verify the accuracy of the data presented on this receipt. **If an error is noted on this Filing Receipt, please write to the Office of Initial Patent Examination's Filing Receipt Corrections. Please provide a copy of this Filing Receipt with the changes noted thereon. If you received a "Notice to File Missing Parts" for this application, please submit any corrections to this Filing Receipt with your reply to the Notice. When the USPTO processes the reply to the Notice, the USPTO will generate another Filing Receipt incorporating the requested corrections**

Applicant(s)

Nigel Cook, El Cajon, CA;

Hanspeter Widmer, Solothurn, SWITZERLAND;

Lukas Sieber, Fribourg, SWITZERLAND;

Power of Attorney: The patent practitioners associated with Customer Number 74162

If Required, Foreign Filing License Granted: 03/17/2008

The country code and number of your priority application, to be used for filing abroad under the Paris Convention, is **US 61/034,116**

Projected Publication Date: None, application is not eligible for pre-grant publication

Non-Publication Request: No

Early Publication Request: No

**** SMALL ENTITY ****

Title

Packagin of a Wireless Power device

PROTECTING YOUR INVENTION OUTSIDE THE UNITED STATES

Since the rights granted by a U.S. patent extend only throughout the territory of the United States and have no effect in a foreign country, an inventor who wishes patent protection in another country must apply for a patent in a specific country or in regional patent offices. Applicants may wish to consider the filing of an international application under the Patent Cooperation Treaty (PCT). An international (PCT) application generally has the same effect as a regular national patent application in each PCT-member country. The PCT process **simplifies** the filing of patent applications on the same invention in member countries, but **does not result** in a grant of "an international

page 1 of 3

patent" and does not eliminate the need of applicants to file additional documents and fees in countries where patent protection is desired.

Almost every country has its own patent law, and a person desiring a patent in a particular country must make an application for patent in that country in accordance with its particular laws. Since the laws of many countries differ in various respects from the patent law of the United States, applicants are advised to seek guidance from specific foreign countries to ensure that patent rights are not lost prematurely.

Applicants also are advised that in the case of inventions made in the United States, the Director of the USPTO must issue a license before applicants can apply for a patent in a foreign country. The filing of a U.S. patent application serves as a request for a foreign filing license. The application's filing receipt contains further information and guidance as to the status of applicant's license for foreign filing.

Applicants may wish to consult the USPTO booklet, "General Information Concerning Patents" (specifically, the section entitled "Treaties and Foreign Patents") for more information on timeframes and deadlines for filing foreign patent applications. The guide is available either by contacting the USPTO Contact Center at 800-786-9199, or it can be viewed on the USPTO website at <http://www.uspto.gov/web/offices/pac/doc/general/index.html>.

For information on preventing theft of your intellectual property (patents, trademarks and copyrights), you may wish to consult the U.S. Government website, <http://www.stopfakes.gov>. Part of a Department of Commerce initiative, this website includes self-help "toolkits" giving innovators guidance on how to protect intellectual property in specific countries such as China, Korea and Mexico. For questions regarding patent enforcement issues, applicants may call the U.S. Government hotline at 1-866-999-HALT (1-866-999-4158).

LICENSE FOR FOREIGN FILING UNDER

Title 35, United States Code, Section 184

Title 37, Code of Federal Regulations, 5.11 & 5.15

GRANTED

The applicant has been granted a license under 35 U.S.C. 184, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" followed by a date appears on this form. Such licenses are issued in all applications where the conditions for issuance of a license have been met, regardless of whether or not a license may be required as set forth in 37 CFR 5.15. The scope and limitations of this license are set forth in 37 CFR 5.15(a) unless an earlier license has been issued under 37 CFR 5.15(b). The license is subject to revocation upon written notification. The date indicated is the effective date of the license, unless an earlier license of similar scope has been granted under 37 CFR 5.13 or 5.14.

This license is to be retained by the licensee and may be used at any time on or after the effective date thereof unless it is revoked. This license is automatically transferred to any related applications(s) filed under 37 CFR 1.53(d). This license is not retroactive.

The grant of a license does not in any way lessen the responsibility of a licensee for the security of the subject matter as imposed by any Government contract or the provisions of existing laws relating to espionage and the national security or the export of technical data. Licensees should apprise themselves of current regulations especially with respect to certain countries, of other agencies, particularly the Office of Defense Trade Controls, Department of State (with respect to Arms, Munitions and Implements of War (22 CFR 121-128)); the Bureau of Industry and

Security, Department of Commerce (15 CFR parts 730-774); the Office of Foreign Assets Control, Department of Treasury (31 CFR Parts 500+) and the Department of Energy.

NOT GRANTED

No license under 35 U.S.C. 184 has been granted at this time, if the phrase "IF REQUIRED, FOREIGN FILING LICENSE GRANTED" DOES NOT appear on this form. Applicant may still petition for a license under 37 CFR 5.12, if a license is desired before the expiration of 6 months from the filing date of the application. If 6 months has lapsed from the filing date of this application and the licensee has not received any indication of a secrecy order under 35 U.S.C. 181, the licensee may foreign file the application pursuant to 37 CFR 5.15(b).

Packaging of a Wireless Power Device

(pp21)

[0001] Our previous applications and provisional applications, including, but not limited to, US Patent application number 12/018,069, filed January 22, 2008, entitled "Wireless Apparatus and Methods", the disclosure of which is herewith incorporated by reference, describe wireless transfer of power.

[0002] The transmit and receiving antennas are preferably resonant antennas, which are substantially resonant, e.g., within 10% of resonance, 15% of resonance, or 20% of resonance. The antenna is preferably of a small size to allow it to fit into a mobile, handheld device where the available space for the antenna may be limited. An embodiment describes a high efficiency antenna for the specific characteristics and environment for the power being transmitted and received.

[0003] Antenna theory suggests that a highly efficient but small antenna will typically have a narrow band of frequencies over which it will be efficient. The special antenna described herein may be particularly useful for this kind of power transfer.

[0004] One embodiment uses an efficient power transfer between two antennas by storing energy in the near field of the

transmitting antenna, rather than sending the energy into free space in the form of a travelling electromagnetic wave. This embodiment increases the quality factor (Q) of the antennas. This can reduce radiation resistance (R_r) and loss resistance (R_l).

[0005] In one embodiment, two high- Q antennas are placed such that they react similarly to a loosely coupled transformer, with one antenna inducing power into the other. The antennas preferably have Q s that are greater than 1000.

[0006] The remainder of this application discusses further operations.

**Report D5-1 Wireless power - motivation, generic
system, product ideas, technological challenges and
risks**

References

[ICN98] International Commission on Non-Ionizing Radiation Protection, "Guidelines for
Limiting Exposure to Time-Varying Electric, Magnetic and Electromagnetic Fields (Up
to 3 GHz)

[SP] www.splashpower.com

**Report D5-1 Wireless power - motivation, generic
system, product ideas, technological challenges and
risks**

Acronyms

BOM	Bill Of Material
ICNIRP	International Commission for Non-Ionizing Radiation Protection
INIRC	International Non-Ionizing Radiation Committee
PCB	Printed Circuit Board
PED	Personal Electronic Devices
RFID	Radio Frequency Identification
SAR	Specific energy Absorption Rate

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

1 Introduction

This document has been prepared for Nigel Power LLC as a first deliverable of WP5 'Applications & Product ideas' of an extended activity called 'Prototyping Towards Product'.

This document has for purpose to

- motivate wireless power
- define a generic break down of a wireless energy transfer system and to describe each subsystem part and function
- to describe presently envisaged applications and product ideas
- to discuss the major technological challenges and potential risks

The document is considered as working document that will be updated in the course of the project.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

2 Motivation for wireless powering & charging

The following statement has been adopted from [SP] and slightly modified and complemented.

Increasing number of battery powered electronic devices

The number of battery powered electronic devices and gadgets used in daily life is steadily increasing. The most important are listed in the following:

- Communications handsets: mobile phones, cordless phones
- Infotainment: Music (MP3) players (diskman, ipod, etc.), Mobile TV, portable audio broadcast receivers
- Photo/video: Digi/video cams
- Wireless peripherals: Bluetooth headsets, cordless microphones, etc.
- Time & navigation: wrist watches/computers, GPS devices
- IT: PADs, Laptops, cordless keyboards & mice, etc.
- Household: Electronic clocks, thermometer, weather stations, pocket calculators, etc.
- Medical: hearing aids, cardiac pacemakers, etc.
- Sport: stopwatches, avalanche beacons, bike computers, bike lamps, pocket lamps, pulse monitors, etc.

Wireless communications has brought certain freedom of wires but recharging requires to regularly tether communication devices to a wall socket. Many other electronic devices use non re-chargeable batteries requiring frequent replacement producing an environmental burden.

No standard charging interface

Almost every re-chargeable device requires its own wall charger. There is no standard charging interface. It is a problem to have the right charger at hand particularly for people on travel. It often happens that people arrive at their travel destination and find that they have forgotten one of their chargers.

Battery technologies have improved, but Personal Electronic Devices (PEDs) in average are getting more power-hungry due to added features and increased usage (e.g. mobile phone with integrated digicam, colour screen, gaming and MP3 players), thus effectively resulting in reduced instead of expanded autonomy time.

Getting power to portable devices has been the focus of a series of recent products that attempt to resolve traditional charging frustrations.

- Wind-up chargers
- zinc-air power packs
- USB chargers
- multi-tipped universal chargers

have solved specific problems for niche market sectors, but none has met with widespread success.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

People don't want to have to think about charging their devices

They just want to use them. For most people, charging and replacing batteries have become a headache and a fundamental part of their day-to-day routines.

We have to remember to change batteries and to charge regularly and we need to have the right charger at hand. We have to free up wall sockets so we can plug in. Moreover, batteries in cordless keyboards and mice are rendering an office IT infrastructure unreliable.

People also have to remember to take a collection of wall-warts with them when travelling and they are suffering from considerable extra weight and bulk in their luggage.

The spaghetti of cables

Desk environments in homes and offices turn more and more into a spaghetti of cables.

A sustainable and standardised powering infrastructure

What is needed is a sustainable infrastructure that users can tap into to power-up. In much the same way that the GSM standard supports a global user group with all sorts of different terminal hardware, a universal standard for powering portable devices could have huge benefits - not least for device OEMs who could look forward to not having to provide a charger with every device they ship.

Establishing a universal power standard has in the past been constrained partly by the mechanics. For example, standardising on a device's connector or charging contacts. Size and shape of these power interfaces will often too much constrain the designs. Moreover, there is the problem of dealing with different power requirements of different devices. This all explains why so little progress has been made.

Wireless powering technology an attractive alternative

A move to a different style of charging using wireless power technology can sidestep many of these issues. Inductive coupling based on time variant (AC) magnetic fields is a suitable technique for such purposes. Non-resonant or low-Q-factor resonant circuits may be used if the device to be recharged is in close proximity of an inductive power source. High-Q-factor resonant circuits enable to power devices in the vicinity of a powering station.

In any case there are no more wires, connectors or contacts between the powering station and the device. A solution that is also advantageous in regard to hermetically sealed (water proof) electronic devices.

This solution would even allow a user to power or charge a selection of devices with different power requirements at the same time.

The vision of wireless powering

The vision for wireless powering technology is more than just introducing some new inductive chargers. It may create a new infrastructure so that people have everywhere opportunities to recharge their electronic devices and do not need to worry about plugging five devices into five separate chargers. A wireless charging zone may be in a friend's house, a cafe, restaurant, hotel or airport lounge. Wherever people go, they would know that they can re-power their devices what ever brand or standard they are using.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

3 Generic system break down

3.1 Overview

The generic wireless energy transfer system to be considered may be divided into three major subsystems

- The energy source (energy transmitter)
- The energy sink (energy receiver)
- Energy relay (parasitic antenna) optional to extend service coverage area/range of a system

These major subsystems may be broken down in parts and functions as shown in the figures below. A description of these functions in more detail is provided in the following subsections.

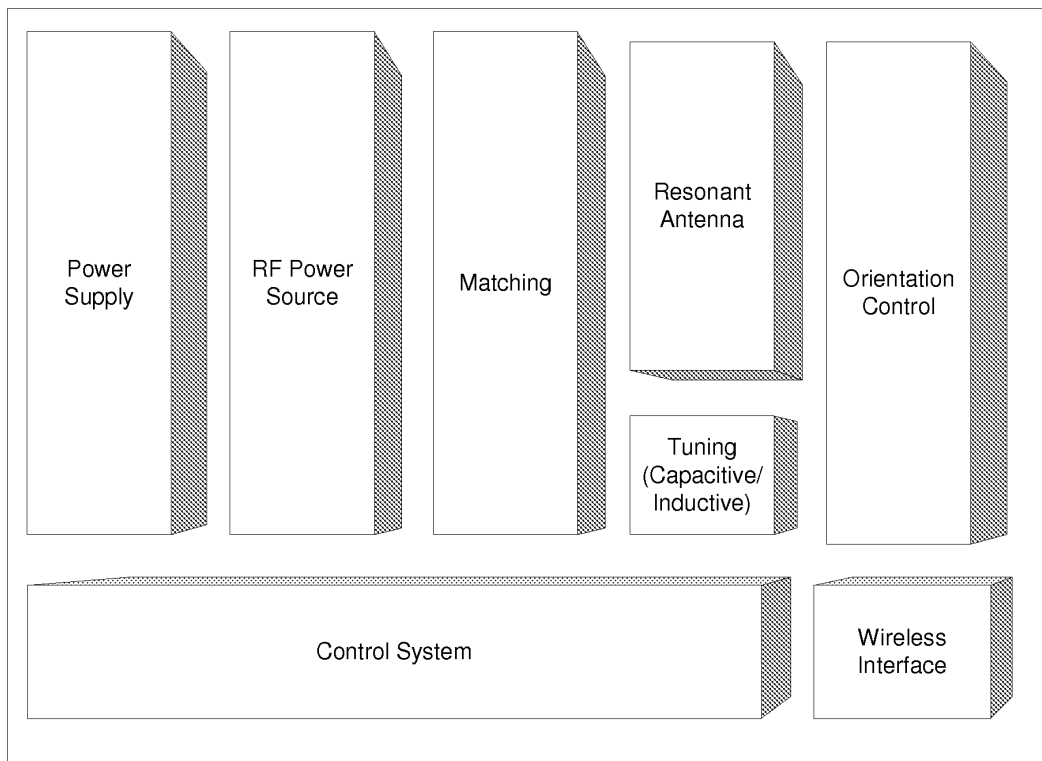


Figure 3-1: The generic energy source (Energy transmitter)

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

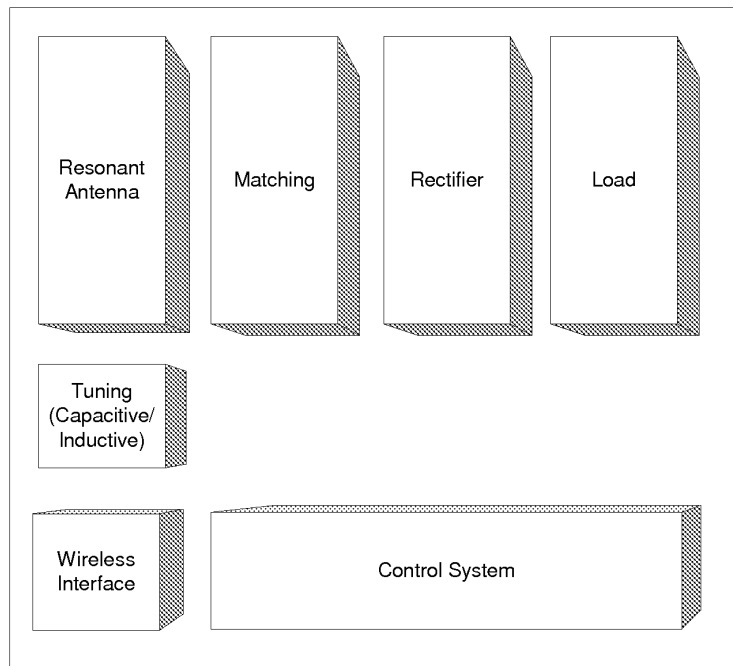


Figure 3-2: The generic energy sink (Energy receiver)

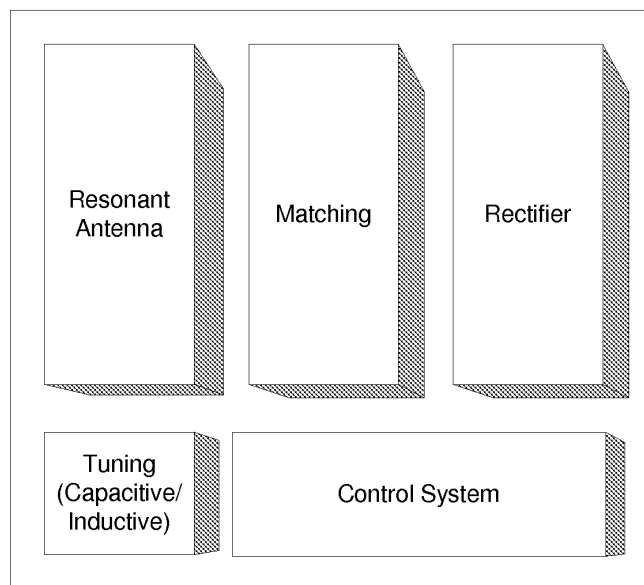


Figure 3-3: The generic energy relay (parasitic antenna)

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

3.2 Subsystem descriptions

3.2.1 Energy source (transmitter)

3.2.1.1 Overview

The generic wireless energy source consists of the following subsystem parts and functions

- The power supply
- The RF power source
- Matching
- Resonant antenna
- Tuning
- Orientation control
- Control system
- Wireless interface

3.2.1.2 Power supply

Generally a high efficiency switched-mode power supply will be used to produce the DC voltage required by the RF power stage. With state-of-the-art electronics very high conversion efficiencies (> 95%) can be achieved. Depending on application, an AC/DC converter or a DC/DC converter (e.g. for automotive applications) will be required. For the transmitters own control functions a constant voltage but low wattage may also be required.

In special solutions/applications the power supply may be omitted or may be only a rectifier.

In an adaptive system this voltage may have to be variable and controlled by the transmitters control system.

3.2.1.3 RF power source

The RF power source may be a non-linear high-efficiency power stage using power switches (Transistors, FETs, etc.) driven by a square wave oscillator.

For vicinity coupling systems operated with higher magnetic field strength the use of a fixed, well defined and stable frequency as generated from a crystal oscillator is preferable with respect to frequency regulatory issues. A common frequency may be defined on an international basis for such applications e.g. at

- 13.56 MHz (ISM-band) in the HF band
- around 135 kHz (ISM-band) in the LF band

Therefore it is assumed that the energy transmitter would include a crystal oscillator as frequency reference. Frequency generation may however be considered as part of the control system.

For transmitters operating in the VLF/LF range a power efficient half-bridge 'inverter' circuit is typically employed. This stage may be modelled by a low impedance source (voltage source) with a rectangular waveform.

Assuming a resonant antenna system, the antenna current as generated by the rectangular voltage waveform will be smoothed and becomes sinusoidal. The resonant circuit is a mean to suppress harmonics emissions. In case of a receiver with close proximity coupling the loaded

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

Q-factor may become so low that there is no significant wave shaping effect (system frequency response becomes broadband). In such case however, low harmonic radiation is expected since antenna currents on transmitter and receiver will drop to low levels also partially compensating themselves. To a certain extent, harmonic radiation potential and wave shaping effect go hand in hand so that harmonic radiation may always be kept below unwanted emission limits.

Power and efficiency control may be accomplished through changing the DC supply power and/or the duty cycle of the squarewave driving the 'inverter'.

3.2.1.4 Matching

No specific antenna matching circuit may be required in the transmitter. Assuming a loop/coil antenna the use of an anti-reactor (capacitor) to compensate for the inductive reactance of the loop/coil may be enough. The output of the low impedance RF power source may be directly connected to the resonant tank circuit (series resonant circuit). To preserve high efficiency this requires however the source impedance (resistance) of the RF power stage to be considerably lower than the resonance resistance of the tank circuit, such that only a small percentage of generated power is dissipated in the source resistance. The source-to-resonance resistance ratio may be controlled to a certain extend through antenna design parameters (L/C ratio).

3.2.1.5 Resonant antenna

In a magnetically (inductively) coupled system, the antenna is generally a multi-turn loop (coil). At higher frequencies (HF) single turn loops may be used. The antenna coil must be designed to withstand the high voltages and currents resulting when the transmitter subsystem is unloaded (no receivers within range). It must provide a Q-factor as high as possible since this Q-factor will limit transfer efficiency at the fringe of service coverage and range.

It is expected that in a real system implementation Q-factors up to 300 are achievable at LF and up to 600 in the HF frequency range (13.6 MHz). In non-integrated laboratory samples Q-factors twice as high may be achievable.

Whilst silver plated copper tube may be adequate material to build a HF loop, thin well insulated wire or thicker stranded wire (litz wire) is typically used at LF, depending on the targeted L/C ratio and the power rating.

At LF, the antenna coil may provide taps for matching or tuning purposes. At HF the use of a special coupling loop/coil (acting as an up-transformer) is an adequate method to match to the impedance of the antenna. This method however is limited in its adaptability to the various conditions that may occur in practice.

3.2.1.6 Tuning

Assuming a fixed and defined operating frequency (crystal controlled), tuning of the resonance frequency antenna is required mainly to compensate for detuning effects caused by

- extraneous objects (metallic objects at LF and metallic and dielectric objects at HF)
- detuned power receivers in close proximity
- variation of source impedance

Tuning may also compensate for component tolerances, ageing, etc.

Tuning should be automatically executed by the transmitters control system according to a defined procedure.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

A fractional tuning range in the order of +/- 10% may be desirable and also sufficient in most scenarios.

To tune a resonant antenna the following parameters may be changed

- Anti-reactance (capacitance)
- Reactance of the inductive part of the antenna system

Capacitive tuning

may be accomplished by

- mechanically tuneable capacitors (driven by mini-motor/actuator)
- electrically tuneable capacitors (dielectric permittivity tuning)
- Capacitor bank (library) and electronic or mechanical switches (RF relays)

Varactor diode tuning may be excluded at high voltages. The introduction of a varactor diode would likely unacceptably deteriorate the antenna Q-factor and likely cause excessive harmonics levels.

Inductive tuning

Inductive tuning at LF may be accomplished through tapping the antenna coil and using mechanical or electronic switches (tap selectors). A tuneable inductor using movable Ferrite core driven by mini-motor/actuator or permeability tuning using DC current biasing may be used for fine tuning.

Another approach to fine tuning is to introduce a second loop/coil and altering the coupling factor to the main loop/coil by changing its shape or orientation (Variometer principle).

Electronically emulated reactance tuning

Non-conventional tuning methods based on electronically emulated reactance may be thinkable. Such methods would allow emulation of positive and negative reactance thus decreasing and increasing resonance frequency of a tank circuit.

3.2.1.7 Orientation control

In certain applications it may be desirable to control orientation of the transmit loop to maximise energy transfer to a receiver arbitrarily positioned or orientated.

Alternatively, two or even three magnetic field components with orthogonal polarisation may be generated. The sum field vector becomes rotating preventing from reception minima at any receiver orientation and position. Such antenna systems will typically require more power and considerably increase overall system complexity. They are also less suitable for integration e.g. if an antenna system needs to be integrated into an existing product/appliance.

3.2.1.8 Control system

The control system of the transmitter is in charge of

- antenna tuning control
- power and efficiency control
- frequency generation
- other housekeeping functions (e.g. system calibration, etc.)
- radiation exposure control

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

In most applications the position and orientation (coupling factor) of receiver(s) may change requiring the system to adapt to the different scenarios in order to satisfy power demand of each receiver and to maximise overall system efficiency.

In a single receiver system this control problem is considered relatively simple. Both transmitter and receiver may adapt independently converging in maximum transfer efficiency. It appears that no feedback signalling is needed from the receiver to optimally adjust the transmitters parameters. The transmitter control system may use a local model of its tank circuit as well as the receiver circuit. The transmitters control system may determine the model parameters using specific measurements (e.g. of antenna current and voltage, input power, etc.) and calibration routines. Based on this local model the transmitter parameters may be optimised to maximise transfer efficiency and to satisfy the power demand of the receiver.

The multiple receiver scenario imposes a much more complex control problem likely requiring feedback signalling from receivers if overall transfer efficiency must be maximised. Quite different control strategies are required for such scenarios.

Moreover, the system may implement special functions for radiation exposure control e.g. power reduction when persons are approaching the transmit antenna.

3.2.1.9 Wireless interface

A wireless interface is considered optional depending on the solution and application.

The wireless interface may be used for the following functions

- Device detection, identification, authentication
- Communications/signalling between power transmitter and power receiver (device)

Detection, identification and authentication of an energy receiving device is considered analogues to today's RFID systems. Numerous methods and standards exist today for detection, identification, and authentication. In a simple system device detection may suffice. In more sophisticated solutions, device identification and even device authentication might be required.

In the general case communication will be bi-directional. For a simplified approach a unidirectional signalling from the energy receiver to the energy transmitter might suffice.

Data communications/signalling between energy source and energy sink may use the power carrier as communication carrier. Due to the high Q-factor there will however be only limited bandwidth available, thus strongly limiting modulation index and/or transmission speed.

The use of alternative wireless standards such as Bluetooth, Zigbee, etc. operating in other ISM-bands is also thinkable. Many portable devices already support such wireless interfaces that could be used by the energy transfer system.

3.2.2 Energy sink (Receiver)

3.2.2.1 Overview

The generic wireless energy sink consists of the following subsystem parts and functions

- The resonant antenna
- Tuning
- Matching

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

- Rectifier
- Load
- Control system
- Wireless interface

3.2.2.2 Resonant antenna

In a magnetically (inductively) coupled system, the antenna is generally a multi-turn loop (coil). At LF the magnetic antenna may contain a ferromagnetic or ferrimagnetic core e.g. a Ferrite rod antenna.

At higher frequencies (HF) multi-turn loops may be used. The antenna coil must be designed to withstand the high voltages and currents resulting when the receiver subsystem is operated at highest loaded Q or in close proximity of a transmitter. It must provide a Q-factor as high as possible since this Q-factor will limit transfer efficiency at the fringe of service coverage and range. Eddy currents and dielectric losses in the surrounding of a receive antenna will deteriorate its Q-factor. This is particularly true if the antenna is integrated into a device. Integration of an energy receiver is therefore a challenging design problem.

It is expected that in a real system implementation Q-factors up to 150 are achievable at LF and up to 200 in the HF frequency range (13.6 MHz). In non-integrated laboratory samples Q-factors twice as high may be achievable.

Whilst silver plated copper wire may be adequate material to build a HF loop, thin well insulated wire or thicker stranded wire (litz wire) is typically used at LF, depending on the targeted L/C ratio and the power rating.

At LF, the antenna coil may provide taps for matching or tuning purposes. At HF the use of a special coupling loop/coil (acting as an up-transformer) is an adequate method to match to the impedance of the antenna. This method however is limited in its adaptability to the various conditions that may occur in practice.

3.2.2.3 Tuning

Assuming a fixed operating frequency defined by the energy transmitter, tuning of the antennas resonance frequency is required mainly to compensate for detuning effects caused by

- extraneous objects (metallic objects at LF and metallic and dielectric objects at HF)
- detuned power receivers in close proximity
- variation of load impedance

Tuning may also compensate for component tolerances, ageing, etc.

Tuning should be automatically executed by the receivers control system according to a defined procedure.

A fractional tuning range in the order of +/- 10% may be desirable and also sufficient in most scenarios.

Tuning of a high Q resonant receiver integrated in a small portable device is a particular design challenge considering space and BOM constraints.

To tune a resonant antenna the following parameters may be changed

- Anti-reactance (capacitance)
- Reactance of the inductive part of the antenna system

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

Capacitive tuning

may be accomplished by

- mechanically tuneable capacitors (driven by mini-motor/actuator)
- electrically tuneable capacitors (dielectric permittivity tuning)
- Capacitor bank (library) and electronic or mechanical switches (RF relays)

Varactor diode tuning may be excluded at high voltages. The introduction of a varactor diode would likely unacceptably deteriorate the antenna Q-factor and likely cause excessive harmonics levels.

Inductive tuning

Inductive tuning at LF may be accomplished through tapping the antenna coil and using mechanical or electronic switches (tap selectors). A tuneable inductor using movable Ferrite core driven by mini-motor/actuator or permeability tuning using DC current biasing may be used for fine tuning.

Electronically emulated reactance tuning

Non-conventional tuning methods based on electronically emulated reactance may be thinkable. Such methods would allow emulation of positive and negative reactance thus decreasing and increasing resonance frequency of a tank circuit.

3.2.2.4 Matching

In the receiver antenna, specific and likely also re-configurable matching will likely be required in order to optimally adapt the receiver to the wide range of coupling factors that may occur in real usage scenarios. Assuming a loop/coil antenna, an anti-reactor (capacitor) will be used to compensate for the inductive reactance of the loop/coil resulting in a tank circuit resonant at the operating frequency.

In high coupling factor conditions, the rectifier/load may be inserted into the series tank circuit in analogy to the transmitter. However, in low coupling factor conditions the optimum load resistance (maximising power into load) approaches the resonance resistance of the receivers tank circuit, which might be as low as a few Ohms, depending on the tank circuits L/C ratio. In such conditions, a special matching using either a special coupling loop or a taped antenna coil, or a capacitive voltage divider may be needed to transform the impedance imposed by the rectifier/load to the required value.

3.2.2.5 Rectifier

The rectifier converts the AC power induced into the receiver antenna into DC power. It consists of current rectifying electronic components such as diodes with low threshold voltage or electronic circuitry (transistors) that switches synchronously to the received AC.

Ideally, the rectifier should not noticeably dissipate power. Therefore, appropriate antenna matching configuration, and load impedance adaptation is required particularly if simple diode rectifiers are employed. Synchronous rectification is more complex but provides the potential of very low power dissipation particularly at low rectifier input voltages (low impedance case).

3.2.2.6 Load

The load includes

- the target load that consumes the transferred energy (e.g. battery of a device, device circuitry)

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

- load imposed by the energy receivers own supply (control functions)
- load impedance adaptation and load power control

the latter is generally accomplished using a DC/DC converter, ideally with minimum power losses. Depending on the load characteristics, it acts as a step-down or a step-up converter (Buck-Boost converter).

3.2.2.7 Control system

The control system of the receiver is in charge of

- antenna tuning control
- power and efficiency control
- Frequency generation (e.g. if the load requires a standard AC mains frequency)
- other housekeeping functions (e.g. system calibration, etc.)

In most applications the receivers position and orientation (coupling factor) may change requiring the receiver to automatically adapt to the different conditions in order to control and maintain power into the load at a desired level and to maximise receivers efficiency.

In a single receiver system this control problem is considered relatively simple. The receiver may adapt independently from the transmitter. It appears that no signalling is required between transmitter and receiver. The receivers control system may use a local model of its tank circuit as well as the receiver circuit. The receivers control system may determine the model parameters using specific measurements (e.g. antenna current and voltage, input power, etc.) and calibration routines. Based on this local model the receivers parameters may be optimised to maximise transfer efficiency and to satisfy the power demand of the receiver.

In a multiple receiver scenario the energy receiver likely must feedback data to the energy transmitter if overall transfer efficiency has to be maximised.

Moreover, the system may implement special functions for radiation exposure control e.g. power reduction when persons are approaching the parasitic antenna.

3.2.2.8 Wireless interface

A wireless interface is considered optional depending on the solution and application.

The wireless interface may be used for the following functions

- Device detection, identification, authentication
- Communications/signalling between power transmitter and power receiver (device)

Detection, identification and authentication of an energy receiving device is considered analogues to today's RFID systems. Numerous methods and standards exist today for detection, identification, and authentication. In a simple system, device detection may suffice. In more sophisticated solutions, device identification and even device authentication might be required.

In the general case communication will be bi-directional. For a simplified approach a unidirectional signalling from the energy receiver to the energy transmitter might suffice.

Data communications/signalling between energy transmitter and energy receiver may use the power carrier as communication carrier.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

The use of alternative wireless standards such as Bluetooth, Zigbee, etc. operating in other ISM-bands is also thinkable. Today many portable devices already support wireless interfaces that could also be used by the energy transfer system.

3.2.3 Energy relay (parasitic antenna)

3.2.3.1 Overview

The generic wireless energy relay consists of the following subsystem parts and functions

- The resonant parasitic antenna
- Tuning
- Matching
- Rectifier
- Load
- Control system
- Wireless interface (optional)

An energy relay may be optionally used to extend coverage/range of a wireless energy transfer system. It receives energy from an energy transmitter and relays it to an energy receiver. The energy relay may be also considered as a parasitic antenna locally amplifying the field strength.

3.2.3.2 Resonant parasitic antenna

In a magnetically (inductively) coupled system, the antenna is generally a multi-turn loop (coil). At higher frequencies (HF) single turn loops may be used. The antenna coil must be designed to withstand the high voltages and currents resulting when the energy relay subsystem is unloaded (no receivers within range) and/or the relay is close to the energy transmitter.

It must provide a Q-factor as high as possible since this Q-factor will limit transfer efficiency at the fringe of the extended service coverage and range.

It is expected that in a real system implementation Q-factors up to 300 are achievable at LF and up to 600 in the HF frequency range (13.6 MHz). In non-integrated laboratory samples Q-factors twice as high may be achievable.

The materials and components needed to build a parasitic antenna may be the same or similar to those used in an energy transmitter.

3.2.3.3 Tuning

Methods of tuning of the resonance frequency of a parasitic antenna are analogues to the energy transmitter.

3.2.3.4 Matching

The purpose and methods of matching may be similar to those of an energy receiver.

3.2.3.5 Rectifier

A rectifier is needed to extract DC power that is locally needed to energise the energy relays own control functions.

The rectifier is analogues to that of the energy receiver and should be as efficient as possible.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

3.2.3.6 Control system

The control system of the energy relay is in charge of

- antenna tuning control
- power and efficiency control

In some applications the relays position and orientation (coupling factor) may change requiring the relay to automatically adapt to the different conditions in order to control and maintain power required for its own purposes (control system).

The relay may adapt independently from the energy transmitter. It appears that no signalling is required between a relay and a transmitter and between a relay and a receiver.

The energy relayed by the parasitic antenna cannot be controlled. It is a function of transmitter and receivers parameters. An energy relay can only be activated or deactivated.

3.2.3.7 Wireless interface

A wireless interface is considered optional depending on the solution and application.

It may be used to

- detect, identify, and authenticate an energy relay
- Activate and deactivate an energy relay
- Transmit information about the operational status of an energy relay

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

4 Applications & Product ideas

4.1 Wireless desktop IT environment

A solution to an entirely wireless desktop IT environment is proposed in which handheld communications terminals and IT peripheral devices are powered or recharged from a central power source via a wireless energy transfer. The preferred technique for wireless energy transfer is based on coupled magnetic resonance using magnetic field antennas (loop, coil) operating either in the LF or HF frequency range.

The PC screen incorporates a power transmitter whose antenna is preferentially embedded in the foot of the screen. The screen foot may be disk-shaped embedding a circular wire loop antenna generating an essentially vertically polarised magnetic field.

Wireless power enabled IT devices as usually placed and operated desktop may receive power from this power transmitter unit. The power transmitter unit as well as the PC flat screen is operated from the standard mains (e.g. 230 V or 110 VAC).

Desktop devices such as keyboard, mouse, and personal electronic devices (mobile phones, music players, PDAs, etc.) integrate a power receiver with a wire loop antenna with a preferentially coplanar orientation to the transmit loop antenna.

For other devices such as cordless phones, digicams, etc. that are usually placed on a recharging station, the wireless power receiver and its antenna may be integral part of the recharging station.

Power receiving devices providing enough space to integrate more effective antennas may also serve as power relays for other low power devices placed nearby.

Figure 4-1 shows an example of a wireless desktop IT environment and Figure 4-2 the coplanar magnetic field coupling between the various devices.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

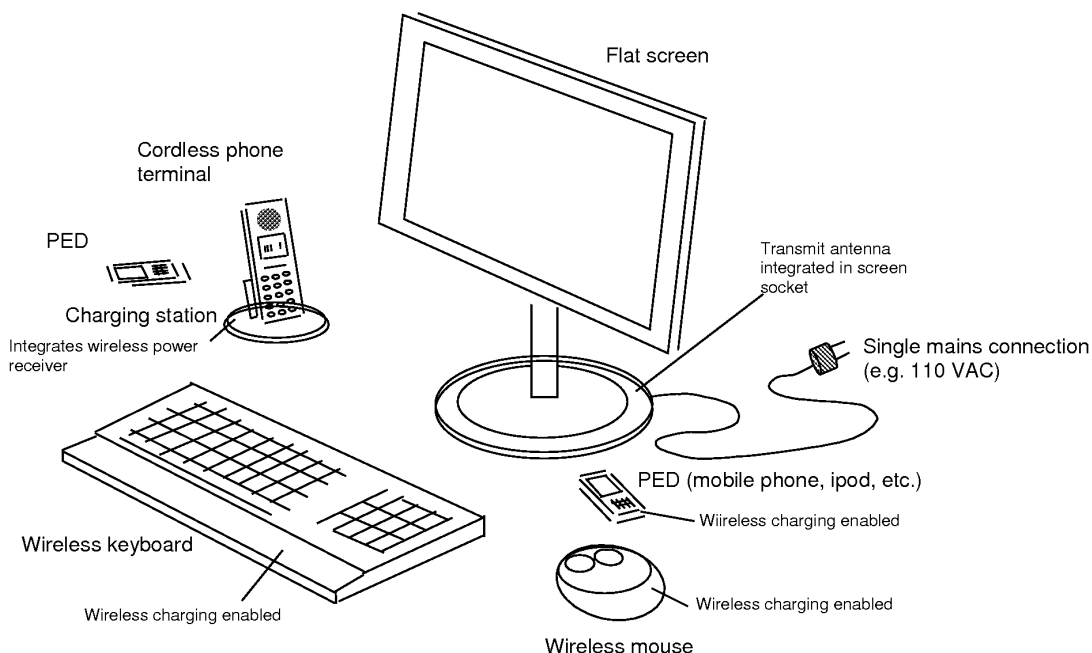


Figure 4-1: Wireless desktop IT environment

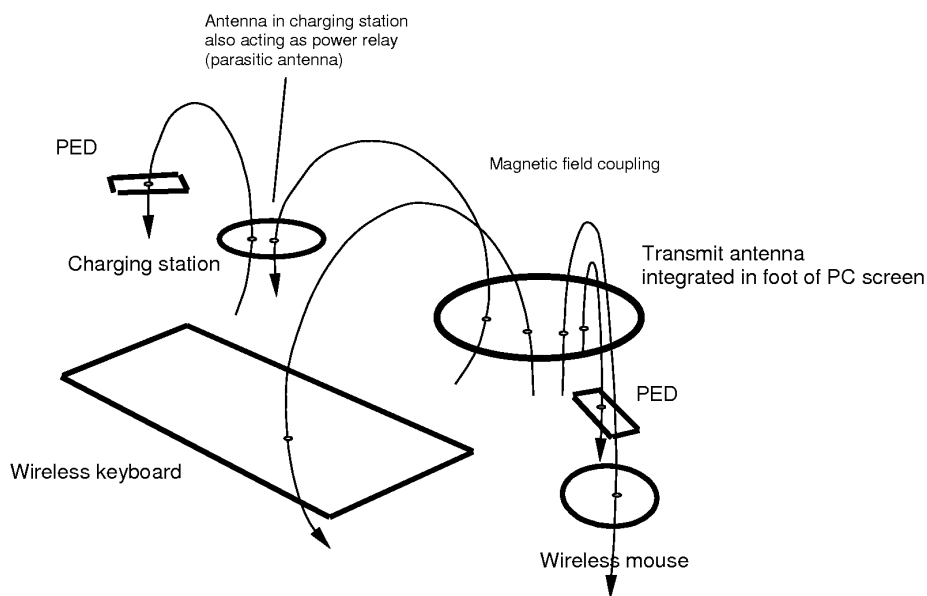


Figure 4-2: Coplanar magnetic field coupling between the various desktop devices

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

4.2 Wireless powering or charging station

Several variants of a wireless powering or charging station for low power portable electronic devices are proposed. An example of a wireless powering or charging station with a portable electronic device (e.g. a cordless phone) is shown in Figure 4-3. In the following when referred to a wireless charging station it may also refer to a wireless powering station.

The preferred technology used for the wireless power link is magnetic coupled resonance. In contrast to ordinary inductive coupling, loosely coupled resonant loop/coil antennas preferentially of high quality factor are used for energy transfer. The operating frequency is preferably either in the LF or HF frequency range.

In variant 1, depicted in Figure 4-4, both the wireless charging station and the portable device integrate a resonant magnetic antenna. The charging station preferably accommodates a loop/coil antenna making best use of the space in the socket of the station, whilst the portable device uses an integrated Ferrite rod antenna or another loop/coil structure with suitable form factor. The wireless charging station (secondary antenna) receives electrical energy from a power base station (primary antenna) and relays it to the portable device (tertiary antenna) placed on the charging station thanks to mutual coupling. This principle is illustrated in Figure 4-5.

Clearly, the portable device may receive energy directly from the power base station. It can be assumed however that the antenna integrated in the portable device may be much less efficient than the antenna integrated in the charging station so that it may not be possible to receive sufficient power directly from the power base station at the desired distance. The effect of the secondary antenna may be considered as that of a parasitic antenna locally magnifying the magnetic field in the vicinity of the charging station increasing the overall efficiency of the receive antenna in the portable device. Therefore Variant 1 is a method to increase the distance of wireless powering and charging.

Placed closely enough to the primary antenna, the portable device may also receive electrical energy directly from the power base station, thus not requiring a special charging station.

Moreover, the magnetic coupling between charging station and portable device may be considered advantageous compared to the conductive coupling using electrical contacts (the classical solution). This is particularly true with respect to soiling, oxidation and different designs of portable devices. (Note that a magnetic coupled charging station may be designed to charge e.g. different types of wireless power-enabled cordless phones).

Variant 2, depicted in Figure 4-6, is similar to variant 1 except that electrical energy received by the wireless charging station is forwarded to the portable device using conductive coupling as in the classical solution.

Variant 3, depicted in Figure 4-7, may be considered as the opposite of variant 2. Here the charging station receives power through a wired connection e.g. directly from the 110/230 V mains or from a wall plug power supply as in classical solutions. However power is forwarded to the portable device based on magnetic coupled resonance.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

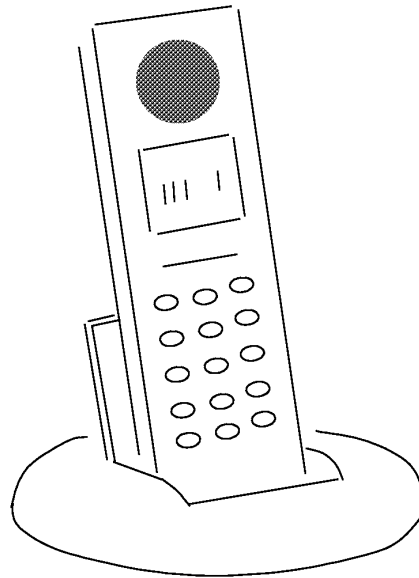


Figure 4-3: Portable device (e.g. cordless phone) placed in wireless charging station

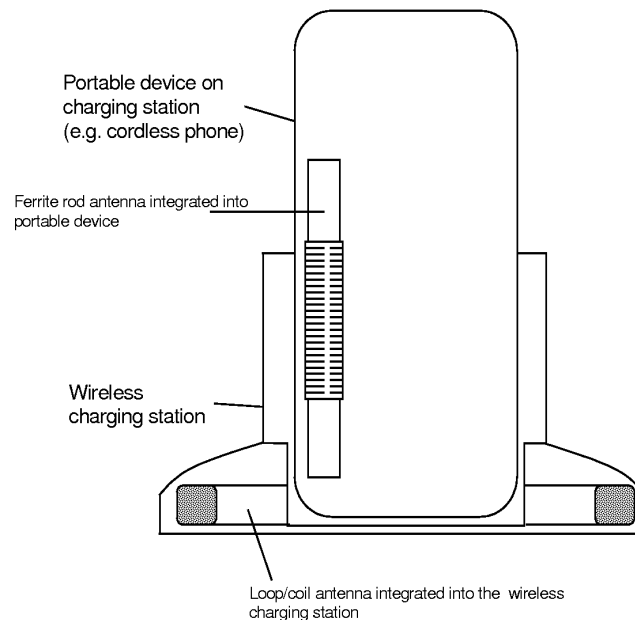


Figure 4-4: Wireless charging station and portable device according to variant 1

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

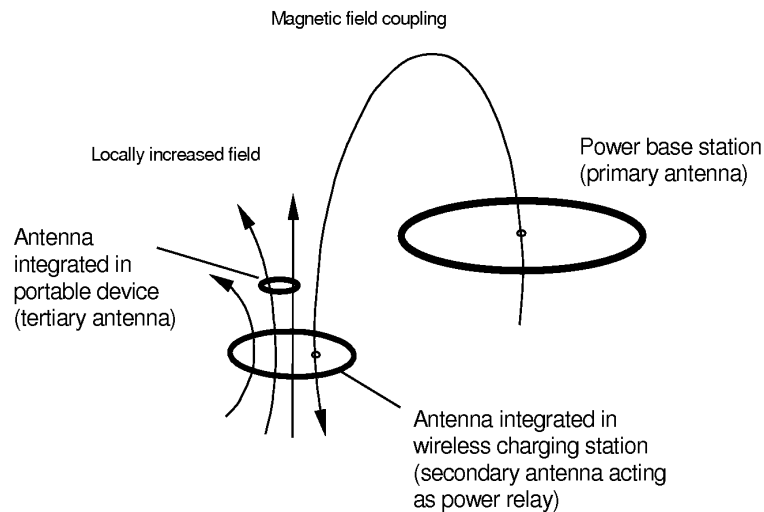


Figure 4-5: Illustration of the principle of variant 1

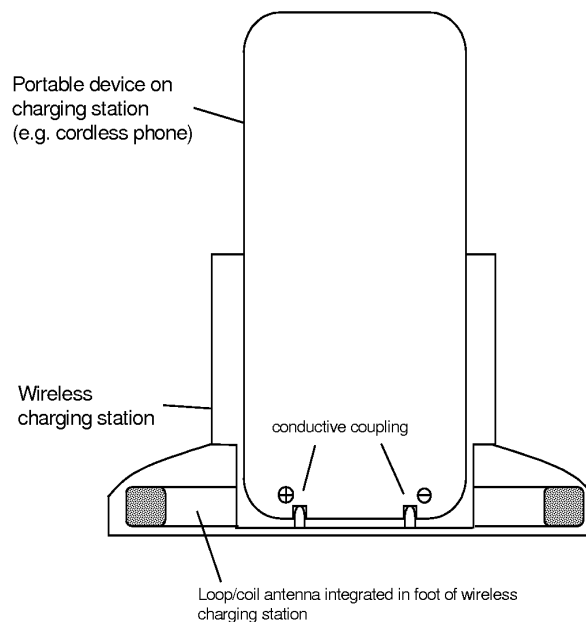


Figure 4-6: Wireless charging station and portable device according to variant 2

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

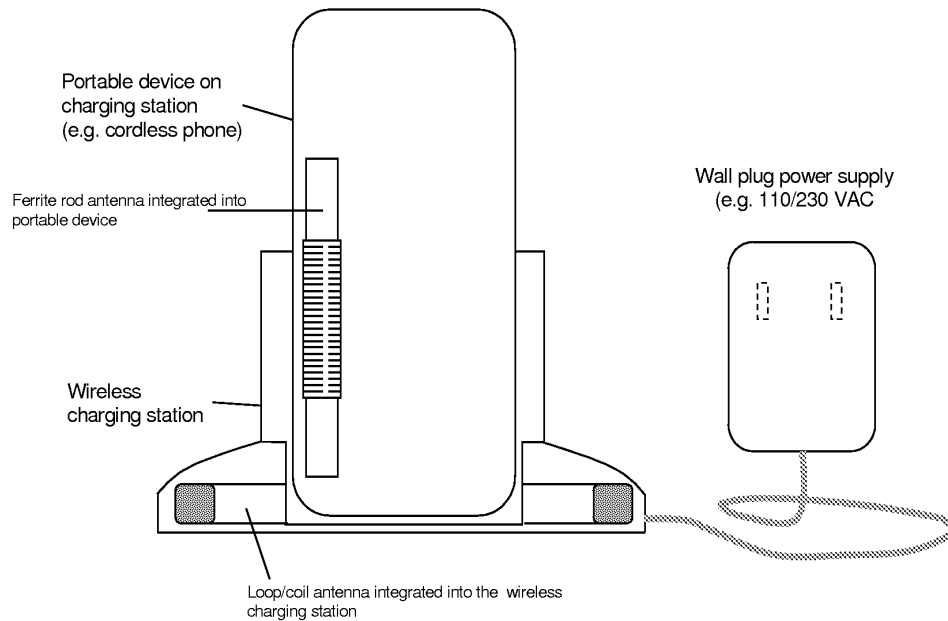


Figure 4-7: Wireless charging station and portable device according to variant 3

4.3 Wireless Power Bridge

4.3.1 Motivation and basic concept

In certain circumstances it may be convenient to transmit power through walls or windows. Some examples:

Example 1: Using a laptop PC or other battery operated devices with limited autonomy on a terrace or balcony where there is no mains socket or the mains socket is too far away for convenience.

Mounting a mains wall socket outdoors is not possible since drilling a hole through the wall is not justifiable or not permitted e.g. because it is an irreversible intervention to someone else's property.

In this example a wireless solution to transfer power through walls or windows may be preferable. This is particularly true, if the indoor component of this wireless power transfer system can be left permanently installed and the outdoor component is a lightweight accessory or a laptop PC that can be easily carried in its transport bag.

Example 2: Powering of sensors mounted to the exterior wall of a house (e.g. burgler alarm system). Installing a power supply cable to all the sensors requires too high effort, or drilling of holes through walls cannot be justified.

In this example a wireless solution to transfer power through walls or windows may simplify installation in a retrofit case.

The proposed wireless solution to transfer power is called 'Wireless Power Bridge'.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

A Wireless Power Bridge may provide a standard AC mains power outlet or a DC power outlet (e.g. 12 VDC). These two variants of a Wireless Power Bridge are sketched in Figure 4-9 and Figure 4-10, respectively. The transmit subsystem may also be considered as producing an invisible local power hot spot that enables easy access to electric power from the other side of a wall using a compatible receiving device.

The proposed Wireless Power Bridge is based on magnetic-field (inductive) coupling between a resonant transmit antenna and a resonant receive antenna and uses an non-modulated carrier frequency ≥ 50 Hz that is appropriate for wireless transmission through a wall or window. The preferred frequency is in the range from 20 kHz to 135 kHz (VLF, LF). A system that directly uses the standard AC mains frequency for wireless energy transfer is also thinkable.

The system is capable of efficiently transferring power through a non-metallic wall of thickness in the range of a few mm up to 40 centimeters also depending on the size of the antenna. This is accomplished through use of two resonant antennas applying the principle of coupled resonance with high Q-factor (typically > 200).

Depending on the dimensioning of the system and the separation of the transmit and receiver antenna (transmission distance) the system may be capable of transferring power up to 100 W to supply e.g. a laptop computer or other devices with similar power consumption.

The proposed system is generally composed of the following components:

- Mains cord to connect to standard AC mains (e.g. 110 VAC/60 Hz or 220 VAC/50 Hz).
- Transmit power converter unit that converts mains AC voltage and frequency (e.g. 110 VAC/60 Hz or 220 VAC/50 Hz) into another voltage and into another frequency (typically > 50 Hz) that may be more appropriate for wireless transmission through a wall or window. In a special case, the transmit power converter unit does not alter the frequency and uses the standard AC mains frequency to transmit power to the receive subsystem.
- Transmit antenna unit (flat panel) that is resonant on the operating frequency
- Receive antenna unit (flat panel) that integrates a multi-turn loop (coil) and a capacitor to achieve resonance at the desired operating frequency.
- A receive power converter unit that integrates an AC/DC or AC/AC frequency converter, which reconverts the frequency used for wireless transmission into the required DC voltage or a standard AC mains voltage and frequency.

Figure 4-10 shows the arrangement to transmit power through a wall and through a window. As distance between transmit and receive antenna and thus the coupling factor may differ significantly for the various use cases, the system automatically adapts to the actual conditions in order to meet power requirements at receive side and to maximise transfer efficiency. Moreover, the system may provide automatic antenna tuning to compensate for possible detuning effects caused by the environment or component tolerances.

The transmit and receive antenna must be co-axially aligned to obtain maximum transfer efficiency. A simple indicator (e.g. LED-based) built into the receive power converter unit may help to find the optimum position of the receive antenna yielding maximum transfer efficiency.

4.3.2 Description of the transmit subsystem

The description of the transmit subsystem refers to the block diagram shown in Figure 4-11. The transmit subsystem is composed of two separate units

- the transmit power converter unit
- the transmit antenna unit

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

4.3.2.1 Transmit power converter unit

The generic transmit power converter unit is composed of the following subunits:

- Rectifier & filter generating the raw DC voltage required by the following stages
- DC/DC converter providing the power that is fed to the transmit antenna unit
- Auxiliary DC/DC converter to supply the frequency generation and control subunit
- Tuning network to maintain precise resonance maximising antenna current.
- Antenna current sense to measure antenna current in terms of magnitude and phase
- Frequency generation and control subunit in charge of
 - generating the frequency used for wireless power transmission, driving the power stage (e.g. the half bridge inverter)
 - automatically controlling all relevant functions of the transmit subsystem which are needed to control power and efficiency of the Wireless Power Bridge.
 - Human interface for manual control of the transmit subsystem if needed (activation/deactivation, power control, etc.)

Assuming a Wireless Power Bridge dimensioned to transfer power up to 100 W, the transmit power converter unit will have a form factor and outer appearance similar to that of an external power supply used to supply e.g. a laptop computer or other appliances of similar power rating.

In the following the individual subunits of the transmit power converter unit are described:

The Rectifier & filter subunit rectifies and filters the AC mains voltage to provide the raw DC voltage required by the DC/DC converter or any replacement of that subunit. The rectifier and filter subunit may include functions that are controlled by the frequency generation and control subunit (control interface A).

Typically, the DC/DC converter is a step-down converter providing an output DC voltage that is lower than its input voltage. In general, the output voltage generated by the DC/DC converter is variable and controlled by the frequency generation and control subunit via control interface B for power control and to achieve maximum energy transfer efficiency. For special solutions, this DC/DC converter may be omitted. That means the power stage (half bridge inverter) is directly supplied by the rectifier and filter subunit.

The auxiliary DC/DC converter subunit provides a fixed DC output voltage to supply the frequency generation and control subunit.

The power stage generating the power carrier used for wireless power transmission is preferably a half bridge inverter using two electronic power switches (FETs or transistors) in 'push-pull' configuration. The power stage is driven and controlled by the frequency generation and control subunit via the control interface B.

In the general case, power and transfer efficiency control is accomplished through modifying two parameters, namely

- the DC supply voltage of the power stage
- the duty cycle (pulse width) of the switching waveform as generated by the frequency generation and control subunit

In case the DC/DC converter does not exist or provides a fixed DC output voltage, power and transfer efficiency is solely controlled by the duty cycle of the switching waveform (pulse width).

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

In case the standard AC mains frequency was directly used for wireless power transmission, the power stage would be constituted e.g. of a phase controlled modulator controlled by the frequency generation and control subunit.

The tuning network is generally needed to ensure that the antenna is operated at its resonance. This is particularly true if a fixed transmission frequency is used.

A fixed and crystal stabilised transmission frequency may be preferable regarding frequency regulatory issues to reduce the risk of harmful electromagnetic interference to other systems. This is particularly true for all applications requiring maximum transmission range and efficiency, thus operated with high 'loaded Q-factor'.

The tuning network compensates for

- possible detuning effects caused by the receive subsystem and/or extraneous objects in proximity of the transmit antenna, as well as by the reactive components in the source impedance of the power stage.
- tolerances (ageing) of components of the transmit antenna unit and its feeder cable.

The tuning network is appropriately controlled by the frequency generation and control subunit via the control interface C.

For special solutions requiring only limited transmission range (e.g. high coupling factor between transmit and receive antenna), the tuning network may be omitted.

The antenna current sense is used by the frequency generation and control subunit to measure the antenna current in terms of magnitude and phase (sense interface D). The current sense ideally should not deteriorate the Q-factor of the antenna system.

The frequency generation and control subunit generates the frequency and the switching waveform required to drive the power stage (Half bridge inverter). Additionally, it measures the transmit antenna current using the antenna current sense and adjusts all relevant operational parameters of the transmit power converter to satisfy power demand by the receiver (within specified limits) also trying to achieve maximum energy transfer efficiency.

In the preferable solution, the frequency generation and control subunit does not need to communicate with its corresponding (peer) entity of the receive subsystem. Both subsystems act independently trying to satisfy power demand by the external load connected to the receive subsystem whilst optimising operating parameters on both transmit and receive side in a manner to converge at maximum energy transfer efficiency.

The frequency and control subunit provides – if needed – a human interface for activating/deactivating the transmit power converter unit and to manually modify parameters.

4.3.2.2 Transmit antenna unit

The transmit antenna unit, which is a pure passive device, is fed by the transmit power converter unit via the antenna feeder cable of length typically 1 m. The feeder cable may be made of quality and for voltage ratings similar to that of a standard double wire AC mains cord.

The transmit antenna unit includes a multi-turn loop (coil) and a high voltage capacitor forming the principal part of a series tank circuit.

The multi-turn loop is made of well insulated copper wire, withstanding the antenna voltage that may occur in the worst case. In a typical design, the r.m.s. voltage may be above 1000 V depending on the systems actual power rating and the specified maximum transmission distance. Assuming an operating frequency in the range between 20 kHz and 135 kHz, preferably an adequately stranded wire (Litz wire) will be used to reduce eddy current losses (skin and proximity effects) and to maximise unloaded Q-factor.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

In a typical design, the capacitor requires to withstand r.m.s. voltages > 1000 V depending on the systems actual power rating and the specified maximum transmission distance.

A typical layout of a flat panel transmit antenna unit is shown in Figure 4-13. The high voltage capacitor is mounted in the interior of the loop to save space and to get maximum loop size for a given outer contour form factor.

The advantage of integrating the HV capacitor into the antenna unit is that high voltages resulting from resonance with a high Q-factor (high loaded Q) are kept in its interior and do not appear neither on the feeder cable nor in the transmit power converter unit thus simplifying design and relaxing certain requirements.

The transmit antenna unit may provide special fixtures that simplify permanent mounting or temporarily suspending of the flat panel antenna to walls or windows (suction cups, suspending handles, etc.).

4.3.3 Description of the receive subsystem

The description of the receive subsystem refers to the block diagram shown in Figure 4-12. The receive subsystem is composed of two separate units

- the receive antenna unit
- the receive power converter unit

4.3.3.1 Receive antenna unit

In the preferred solution, the receive antenna unit is identical to the transmit antenna unit.

For special solutions, the dimensioning of the receive antenna may be different with respect to form factor, constitution, and electrical characteristics. However, the basic layout as shown in Figure 4-13 applies.

The receive antenna unit feeds the receive power converter unit via the antenna feeder cable of length typically 1 m. The feeder cable may be made of quality and for voltage ratings similar to that of a standard double wire AC mains cord.

4.3.3.2 Receive power converter unit

The generic receive power converter unit is composed of the following subunits:

- Antenna current sense
- Tuning and matching network to maintain precise resonance of the receive antenna maximising antenna current and to optimally match the rectifier to the receive antenna.
- Rectifier generating the raw DC voltage required by the following stages.
- DC/DC or DC/AC converter (depending on the application) generating a DC or standard AC mains output, respectively, with a voltage and current satisfying the requirements of the external load connected to the receive subsystem.
- Auxiliary DC/DC converter to supply the frequency generation and control subunit
- Voltage and current sense to measure output voltage and output current into the external load
- Frequency generation and control subunit in charge of
 - automatically controlling all relevant functions and parameters of the transmit subsystem which are needed to control power and efficiency of the Wireless Power Bridge.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

-
- if needed, manual control and modification of settings (via human interface) of the receive subsystem (activation/deactivation, power, voltage and current rating, etc.)
 - if needed, generating the standard AC mains frequency as specified for the external load

Assuming a Wireless Power Bridge dimensioned to transfer power up to 100 W, the receive power converter unit will have a form factor and outer appearance similar to that of an external power supply used to supply e.g. a laptop computer or other appliances of similar power rating.

In the following the individual subunits of the receive power converter unit are described:

The antenna current sense is used by the frequency generation and control subunit to measure the receive antenna current via sense interface D. The current sense ideally should not deteriorate the Q-factor of the antenna system.

The tuning and matching network is generally needed to ensure that the receive antenna is operated at resonance and that the rectifiers input impedance is optimally matched to the receive antenna. This is particularly true for all applications requiring maximum transmission range and efficiency.

The tuning and matching network compensates for

- possible detuning effects caused by the transmit subsystem and/or extraneous objects in proximity of the receive antenna, and by the rectifiers load impedance.
- tolerances (aging) of components of the receive antenna unit and its feeder cable.

The tuning and matching network is controlled and perhaps also reconfigured by the frequency generation and control subunit via the control interface C.

For special applications of the Wireless Power Bridge requiring only limited transmission range (e.g. high coupling factor between transmit and receive antenna), the tuning and matching network may be omitted.

The Rectifier rectifies and filters the AC voltage as induced into the receive antenna providing the raw DC fed to the following stages. The rectifier and filter subunit may include functions that are controlled by the frequency generation and control subunit via control interface A.

The DC/DC or DC/AC converter may be a step-down or step-up converter depending on the application, providing an output voltage and current satisfying the requirements of the external load connected to the receive subsystem. In general, the output voltage or current generated by the DC/DC or DC/AC converter is variable and controlled by the frequency generation and control subunit via control interface B. For special solutions, this converter may be omitted. That means the external load is directly fed by the rectifier.

In case the standard AC mains frequency was directly used for wireless power transmission, the DC/DC or DC/AC converter may be replaced e.g. by a phased controlled modulator controlling output voltage and current into the external load.

The auxiliary DC/DC converter subunit provides a fixed DC output voltage to supply the frequency generation and control subunit.

The frequency generation and control subunit automatically controls all relevant functions and parameters of the receive subsystem to satisfy voltage and current requirements of the external load and to maximise energy transfer efficiency. If needed, it generates the standard AC mains frequency as required by the external load and feeds this frequency to the DC/AC converter subunit via control interface A.

Additionally, it measures the antenna current by means of the antenna current sense, the DC or AC output voltage and current by means of the voltage and current sense, respectively. Based on these measurements, it computes and adjusts relevant operational parameters and

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

configurations of the receive power converter unit in order to satisfy power demand by the receiver (within specified limits) and to maximise energy transfer efficiency.

The receive subsystems acts independently from the transmit subsystem, trying to satisfy requirements by the external load, whilst optimising operating parameters at receive side in a manner to converge at maximum transfer efficiency.

The frequency and control subunit provides – if needed – a human interface for activating/deactivating the receive power converter unit and to manually modify parameters or configurations.

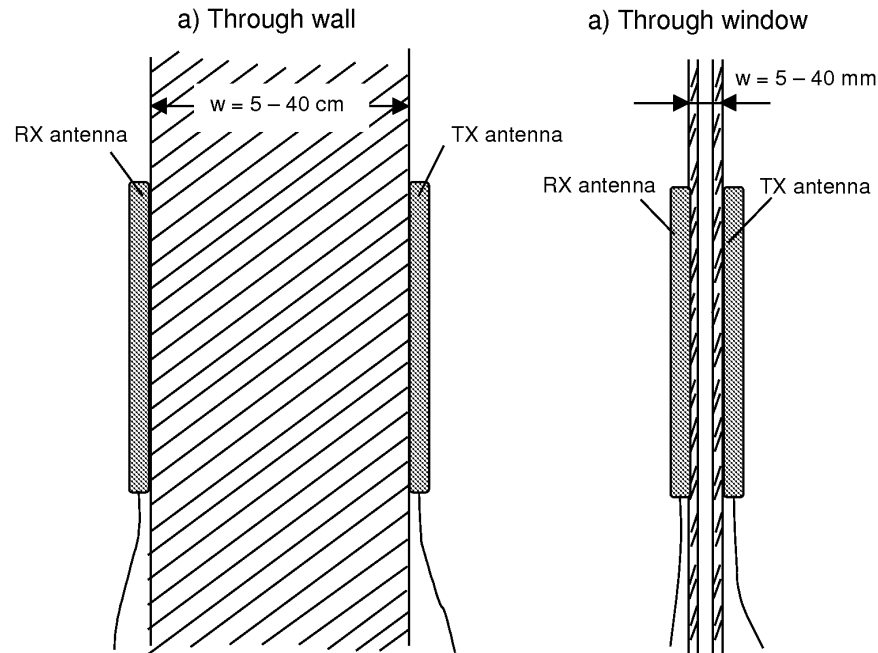


Figure 4-8 Transmission: a) through wall, b) through window

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

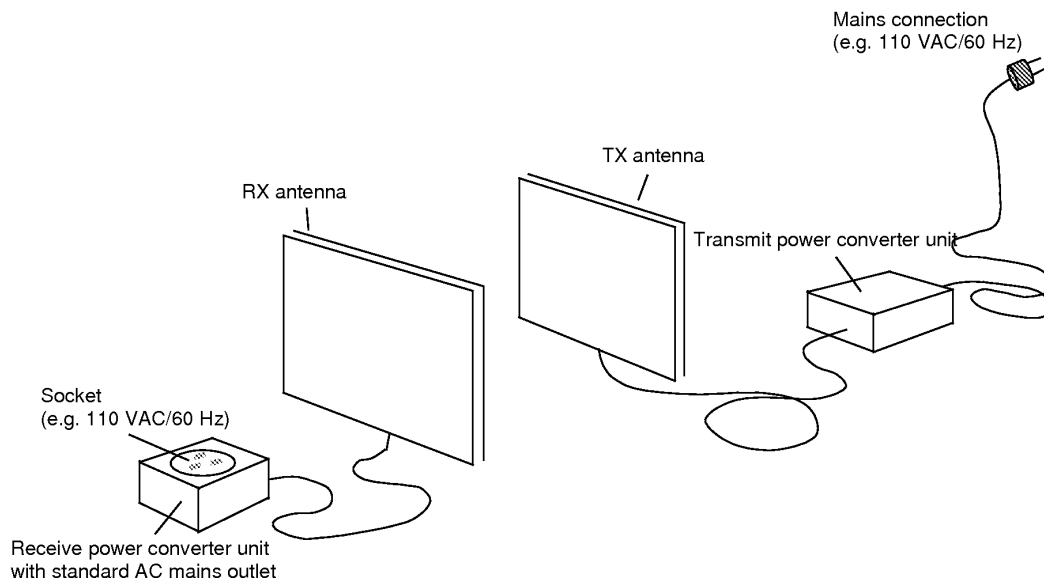


Figure 4-9: Wireless power bridge with a standard AC mains outlet (e.g. 110VAC/60 Hz)

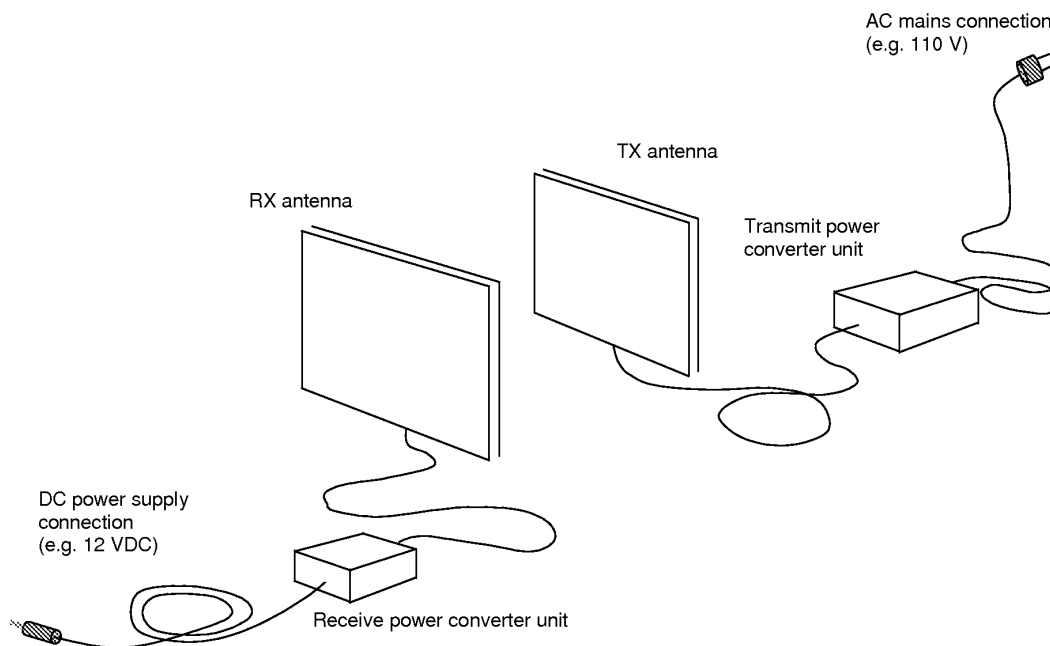


Figure 4-10: Wireless power bridge with a low voltage DC outlet (e.g. 12 VDC)

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

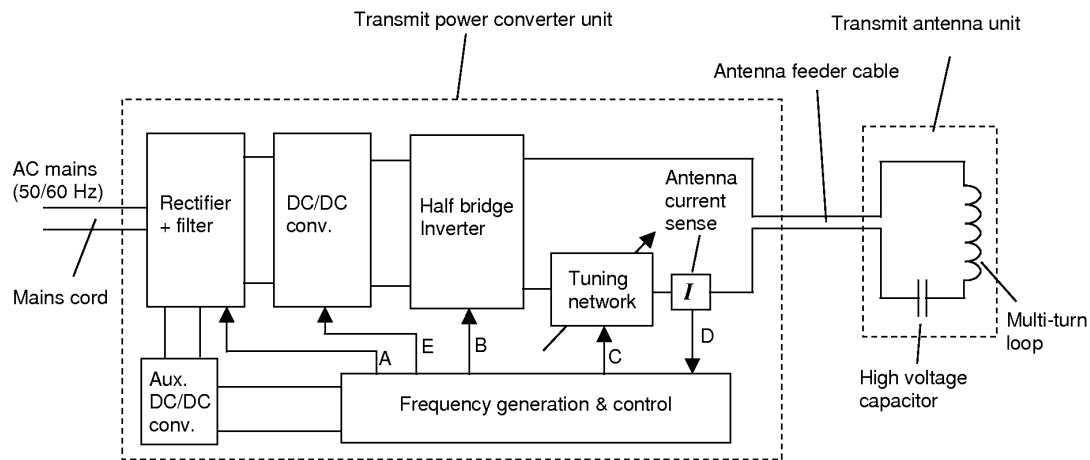


Figure 4-11: Transmit subsystem

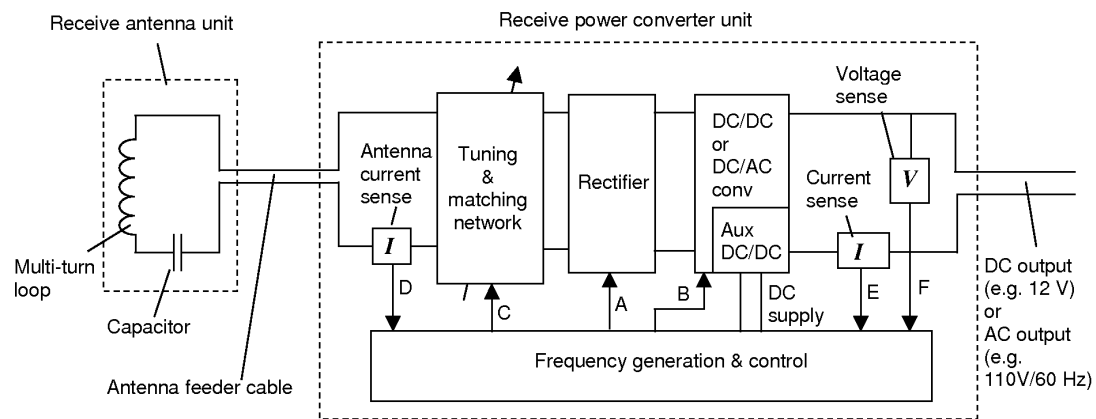


Figure 4-12: Receive subsystem

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

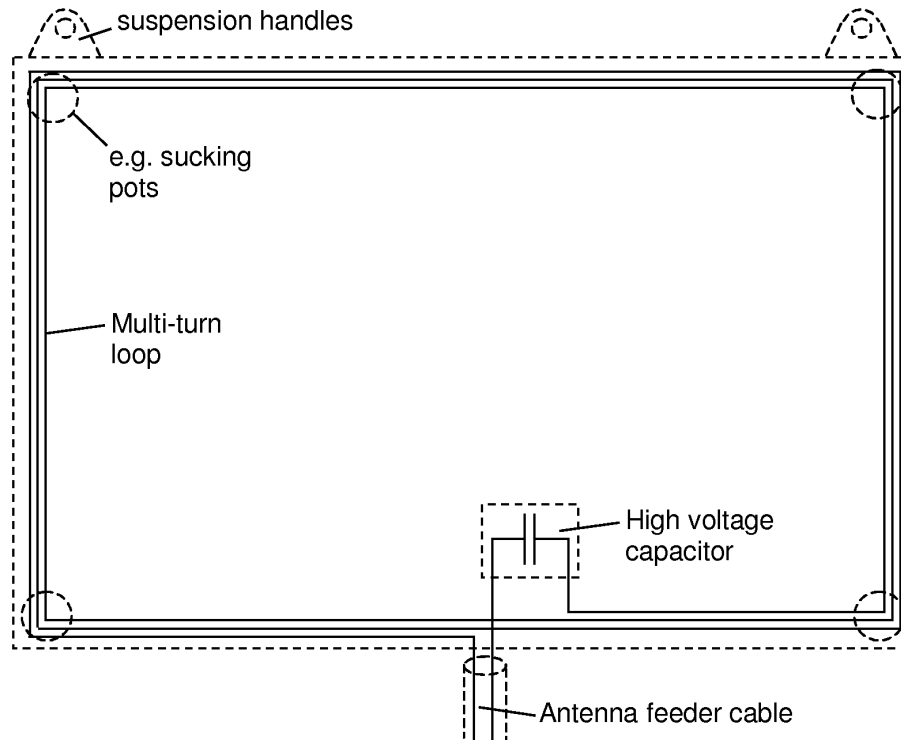


Figure 4-13: Antenna unit used in transmit and receive subsystem



Figure 4-14: Mock-up of a 'Wireless Power Bridge' product

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

5 Major technological challenges

5.1 Realisation of high Q resonant magnetic antennas

5.1.1 Introduction

Efficient wireless energy transfer based on magnetic coupled resonance requires the use of resonant antenna circuits with highest possible quality factor in both energy transmitter and energy receiver.

High Q-factor in conjunction with energy transfer in the order of several watts means high reactive power in the LC tank circuit since the definition of Q-factor is

Equation 5-1
$$Q = \frac{P_{\text{reactive}}}{P_{\text{real}}}$$

High reactive power means high AC voltages/currents across/through the antenna inductor and its anti-reactor (capacitor). The design of high-Q resonant magnetic antennas therefore poses a particular challenge.

5.1.2 Transmit antenna design

At LF, the typically solution is a multi-turn wire loop (coil). There exist three basic approaches to achieve a high Q coil under a given winding cross section constraint. These are the following:

- Approach 1: use thin copper wire and a large number of turns
- Approach 2: use thicker appropriately stranded wire (Litz wire) with a lower number of turns. The Litz wire must consist of individually insulated strands with an optimum diameter for the operating frequency
- Approach 3: use an appropriate ferrite core and Litz wire with a low number of turns

Approach 1 provides a solution with a high impedance coil. This means a high reactance and relatively high loss series resistance that is Q-times lower than the magnitude of the coils reactance where Q refers to the Q-factor of the coil that may normally be assumed as the overall Q-factor of the tank circuit.

Approach 2 results in a solution with a lower impedance coil. This means a lower reactance and relatively low loss series resistance that is again Q-times lower than the magnitude of the coils reactance.

Approach 3 is not recommended due to the high magnetic field strength (saturation) and the resulting low coil Q-factor due to hysteresis losses in the core material.

Approach 1 and approach 2 have their advantages and disadvantages but also their limitations in supporting high voltages and currents resulting at resonance frequency.

Assuming equal Q for both approaches, the voltage that results at resonance will be higher in approach 1. Thus there is also higher risk for arcing/discharge particularly with respect to the thinner wire used in approach 1 (higher electric field strength). From this consideration it may be concluded that approach 2 provides a solution with higher power transfer capability. On the other hand, if too low impedance is targeted, it will become more difficult to find a capacitor with low enough equivalent series resistance and that can support the high current, particularly under space constraints.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

Matching of the antenna to the power stage is a further issue to be considered. A relatively simple and stable transmitter solution is obtained by using a low impedance output power stage (voltage source) (e.g. half-bridge inverter) and by forming a series tank circuit. In order to ensure high efficiency, this solution requires a tank circuit with a series resonance resistance that is considerably higher than the source resistance of the power stage.

For HF (e.g. at 13.6 MHz), similar considerations can be made resulting in similar conclusions. However the number of turns needed will generally be much lower at HF. Instead, much thicker wire and larger wire spacing will be required to mitigate skin and proximity effects. Litz wire optimised for frequencies above 1 MHz is hardly available and probably also not useful due to other design constraints.

Another effect often overlooked degrading Q-factor is energy absorption in lossy materials in the antenna's surrounding. The magnetic and electric fields generated by the antenna can cause

- eddy current losses in non-perfectly conducting materials
- magnetic polarisation (hysteresis) losses in magnetic materials
- electric polarisation losses in dielectric materials

At LF, dielectric losses are normally negligible. Q-factor degradation is mainly due to eddy currents and hysteresis losses in conducting and magnetic materials, respectively.

At HF, eddy currents and dielectric losses are mainly responsible for Q-factor degradation.

In many applications of wireless power, the surrounding of a magnetic antenna is dominated by dielectric materials. In such environment, low impedance antennas that generate higher currents (magnetic fields) but lower voltages (electric fields) generally perform better.

This aspect of Q degradation is of particular importance, if an antenna must be integrated into a device (e.g. into a foot of a PC screen).

Summarising, the following aspects must be considered when designing a high Q transmit antenna:

To obtain maximum inductance at lowest resistance (highest Q-factor) the winding must be as dense as possible meaning that the cross sectional area of the winding must be as low as possible. This is however contradictory to skin and proximity effects and volume needed for wire insulation that must sustain the high resulting voltages, and for power dissipation (copper losses).

Above considerations show that practical designs require thorough analysis, complicated trade-offs and optimisations taking into account all design constraints affecting efficiency of a transmit antenna (volume, form factor, cost, power rating, characteristics and availability of passive and active electronic components, as well as integration aspects).

5.1.3 Receive antenna design

In most wireless power applications, energy receivers have to be integrated into small devices. This is a particular design challenge as there is typically only limited space available. Furthermore, extra BOM needed for enabling wireless power in an electronic device ideally should not significantly increase overall manufacturing costs.

On the other hand, power to be handled in a receiver of a small device will typically not exceed a couple of watts.

At LF, a loop shaped coil either made of very thin well insulated wire or appropriate Litz wire may be used. In principle, approach 1 and 2 as described in above subsection are valid resulting in different coil impedance and capacitance to achieve resonance.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

The effective loop area is the parameter that predominantly affects the performance of the energy receiver. Therefore an effective loop area as large as possible should be aimed. This means the multi-turn loop ideally should fully encompass the device.

Severe Q-degradation due to eddy current losses in all conducting parts of the device must however be expected since the entire electronics is in the interior of the loop where the magnetic field is highest. Furthermore, the use of a metallic housing must be avoided. The high magnetic field strength may also require special measures to avoid interference into the electronics.

Loop antennas that can be folded out would be preferable however increase mechanical complexity and manufacturing costs of a device.

For integrated receivers, approach 3 is particularly interesting since ferrite antennas artificially increase the effective area of the coil and additionally concentrate the magnetic field lines into the Ferrite core. Q-factors up to 100 may be achieved with appropriate Ferrite materials at 135 kHz and for a power of 1 W. However, to achieve an effective area comparable to wire structures encompassing the device largest perimeter, Ferrite rod antennas must be relatively long thus becoming bulky and also heavy. This is the drawback of the use of magnetic permeable materials.

A further solution that may be considered results from a combination of approaches 1 or 2 and 3 using a flat disk-shaped multi-turn loop on a Ferrite substrate (Ferrite backing). This Ferrite substrate ideally should not be thicker than a few Millimetres. Ferrite backing however compromises the effective area of the antenna and therefore its performance.

It appears that designing a magnetic antenna with

- low volume
- low cost
- high performance

integrated in a small electronic device is an extremely challenging design task and requires considerable R&D efforts.

5.2 Antenna tuning

5.2.1 Introduction

Efficient wireless energy transfer based on magnetic coupled resonance requires the use of resonant antenna circuits with high quality factor in both energy transmitter and energy receiver. High Q-factor means low bandwidth thus little tolerance for variations of L and C values due to

- manufacturing tolerances
- ageing
- environmental effects (temperature, extraneous objects interacting with the magnetic or electric field surrounding the LC circuit)
- non-linear and memory effects (e.g. in conjunction with the use of permeable magnetic materials)

Therefore in practical high-Q designs readjusting (tuning) of the resonance frequency is often compulsory.

A resonant antenna system that is automatically tuneable in operation requires an electrically tuneable reactance component in the tank circuit that can withstand either high voltages or high

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

currents and that does ideally does not impair the antennas Q-factor. Whatever its realisation will be, such component tend to

- be bulky
- reduce the overall Q-factor or system efficiency
- considerably increase the cost of the system.

This may be particularly true if a large tuning range is demanded. Therefore, tuning of the resonance frequency of the transmitters and receivers antenna circuit is considered as one of the major design challenges of wireless energy transfer based on coupled resonance.

5.2.2 Transmit antenna tuning

A common method of tuning of a resonant transmit antenna circuit uses a set of capacitors (capacitor bank) in a series or parallel arrangement with RF switches that may be opened or closed to adjust the effective capacitance. This method is particularly useful at LF where mechanically variable capacitors become extremely bulky. Figure 5-1 shows an example of a series resonant transmitter circuit with a tuning capacitor bank in parallel arrangement but in series to the principal capacitor.

Relays or bipolar semiconductor (FET) switches are typically used to add/remove capacitors into/from the circuit. However, as the Q of the LC circuit increases, this method requires an increasing number of tuning capacitors and tuning switches in the capacitor bank to provide a fine tuning capability whilst maintaining the required tuning range. Further, as the Q of the LC tank circuit increases, the voltage supported by the capacitor bank increases, requiring the tuning capacitors and the tuning switches to be rated for higher voltages. Moreover, because the capacitor bank is in series with the antenna circuit, the tuning capacitors and tuning switches must support high currents and relatively high voltages depending on the tuning range. In a real design, a trade-off between tuning range, number of capacitors and voltage rating is required.

Capacitor bank tuning may be combined with a continuously tuneable reactance for fine tuning.

At HF, tuning may be realised with a tuning capacitor of small capacitance in parallel to the principal capacitor (see Figure 5-2). Its realisation may be a mechanically variable capacitor driven by a mini-actuator.

An alternative to capacitance tuning at HF and LF is using a variable inductor. This may be accomplished by

- a tapped antenna coil and electromechanical or electronic switches (tap selector)
- a mechanically adjustable ferrite core driven by a mini-actuator
- permeability tuning of a ferrite core using a DC bias current

Permittivity tuning of a capacitor using a DC bias voltage, which may be considered as the physical dualism to permeability tuning, may also be an option for both HF and LF. However, so far no such components seem to be available that are useful for the frequencies of interest. This may be an interesting topic of further investigation and research.

Another approach to fine tuning is to introduce a second loop/coil and altering the coupling factor to the main loop/coil by changing its shape or orientation (Variometer principle).

Figure 5-4 illustrates a further method that may be considered for fine tuning e.g. in conjunction with a capacitor bank for coarse tuning. This purely electronic method avoids any tuneable reactance components. Instead, it compensates for the antenna current drop in off-resonance conditions simply by increasing the output voltage of the power stage (e.g. half bridge inverter).

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

The power stage may be considered as emulating the voltage resulting at the output of a constant voltage source with a tuneable source reactance (Figure 5-4 a).

It is clear that relatively high output voltages may be required in order to provide useful tuning range thus setting more stringent requirements to the electronic switching elements of the power stage if efficiency shall be preserved.

The fine tuning control loop would be straight forward: sensing the antenna current and controlling the output voltage such that the desired antenna current results.

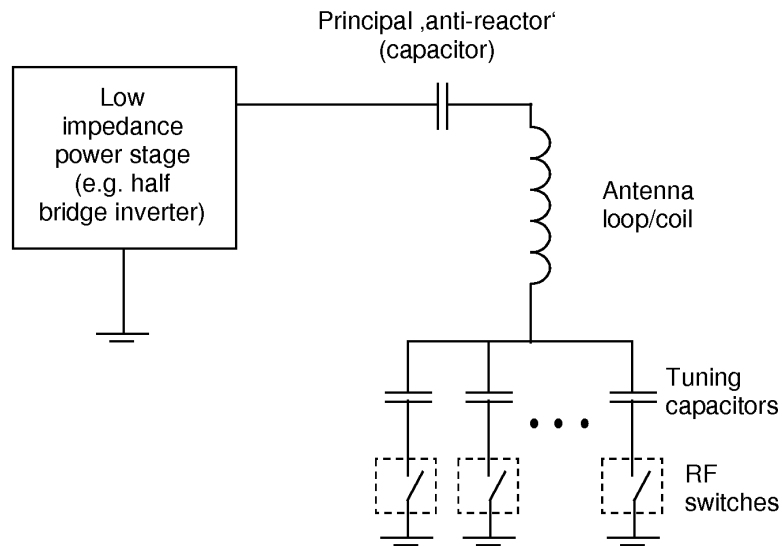


Figure 5-1: Discrete capacitance tuning

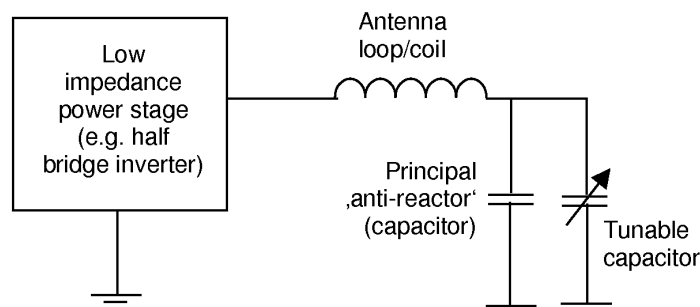


Figure 5-2: Tuning using mechanically variable capacitor

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

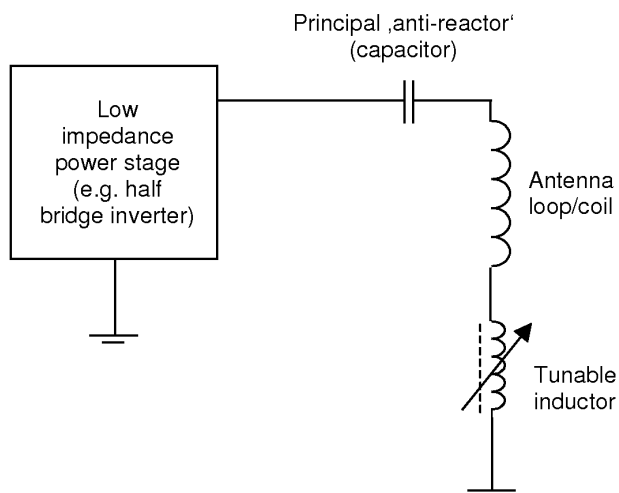


Figure 5-3: Tuning using mechanically variable inductor

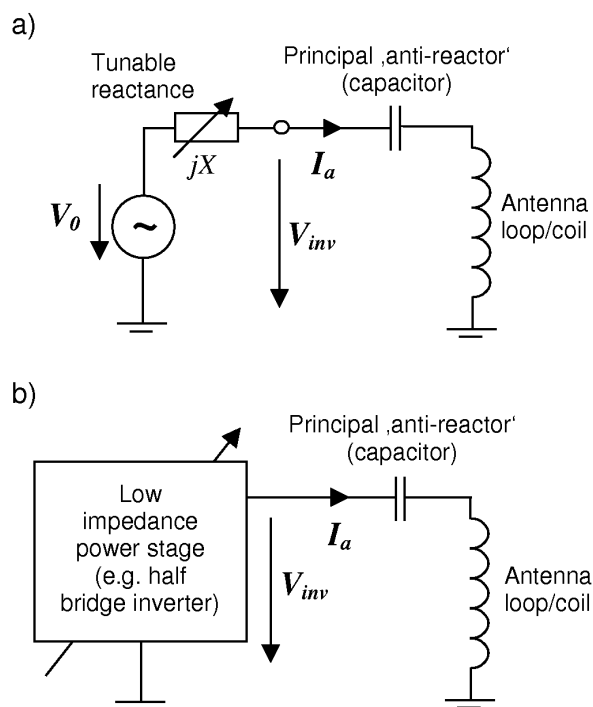


Figure 5-4: Electronic fine tuning using a power stage with variable output voltage

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

5.2.3 Receive antenna tuning

The general principles, methods, considerations, and conclusions described in above subsection will also apply to the tuning problem of a receive antenna. In receiver applications, however, space and cost constraints are typically much more stringent than in transmitters, particularly regarding integration into small portable devices. On the other hand, relaxed requirements with respect to antenna voltages and currents can be expected since small receive antennas will typically

- be rated for lower power, and
- provide lower Q-factor

than transmit antennas.

Capacitor bank tuning as typically used at LF may be less favourable with respect to space constraints.

At HF, tuning may be realised with a tuneable capacitor of small capacitance in parallel to the principal capacitor (see Figure 5-2). Its realisation may be a mechanically variable capacitor driven by a mini-actuator.

A permittivity tuneable capacitor using a DC bias voltage may be a solution for LF and HF. However, so far no such components seem to be available that are useful for the frequencies of interest. Permittivity tuning may be an interesting topic of further investigation and research.

An alternative to capacitance tuning at HF and LF is using a variable inductor. This may be accomplished by

- a tapped antenna coil and electromechanical or electronic switches (tap selector) for coarse tuning
- a mechanically adjustable ferrite core driven by a mini-actuator for fine tuning (see Figure 5-5)
- permeability tuning of a ferrite core using a DC bias current for fine tuning

In conjunction with a ferrite rod antenna (approach 3) tuning may directly be accomplished through altering the inductance of the antenna using

- a mechanically movable coil (sliding coil) driven by a mini-actuator (see Figure 5-6)
- ferrite rod permeability tuning with a DC bias current

Mechanical fine tuning in general appears more suitable in a receiver than permeability tuning requiring an extra DC bias consuming power thus lowering overall system efficiency. Moreover, a mechanically tuneable inductor would keep its state when there is zero power reception and battery in the device is empty, thus capable to self-recover when approaching a wireless power source.

Mechanical tuning of a ferrite rod antenna is particularly interesting as it does not require any additional components in the tank circuit thus minimum impact on Q-factor.

Figure 5-7 illustrates a further method that may be considered for fine tuning a receive antenna e.g. in conjunction with a capacitor bank for coarse tuning. This purely electronic method avoids any tuneable reactance components. Instead, it uses switched-mode power conversion techniques to create antenna load impedance that can be varied in terms of both resistive (real) part and reactive (imaginary) part. The reactive part adds reactance into the series tank circuit thus changing its resonance frequency. Electronic tuning is certainly an interesting topic of further investigation and research.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

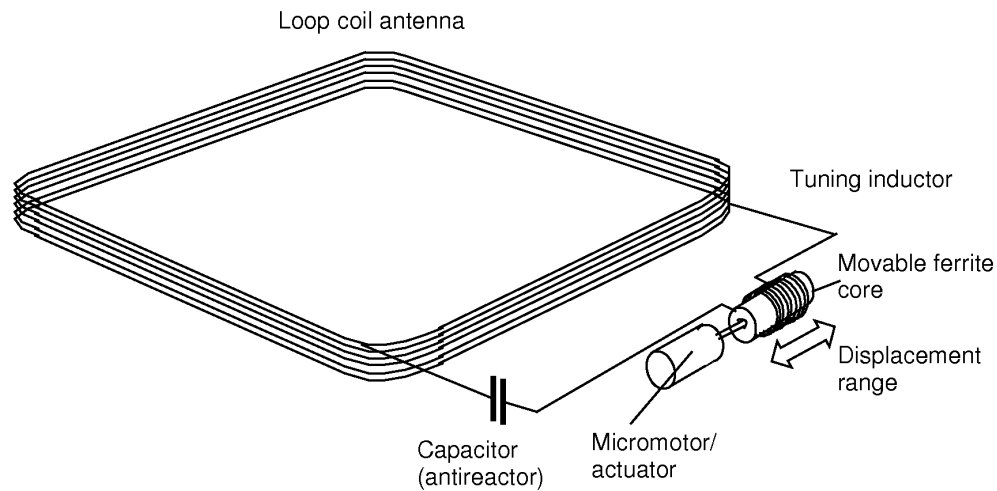
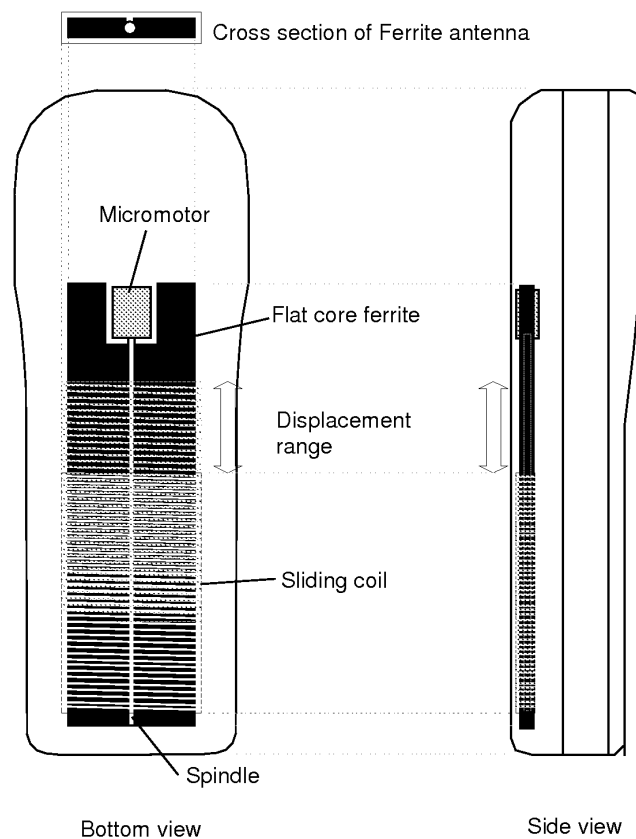


Figure 5-5: Tuning of a resonant loop antenna using a mechanically tuneable inductor



Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

Figure 5-6: Tuning of a ferrite rod antenna integrated in a handheld device by means of a movable coil

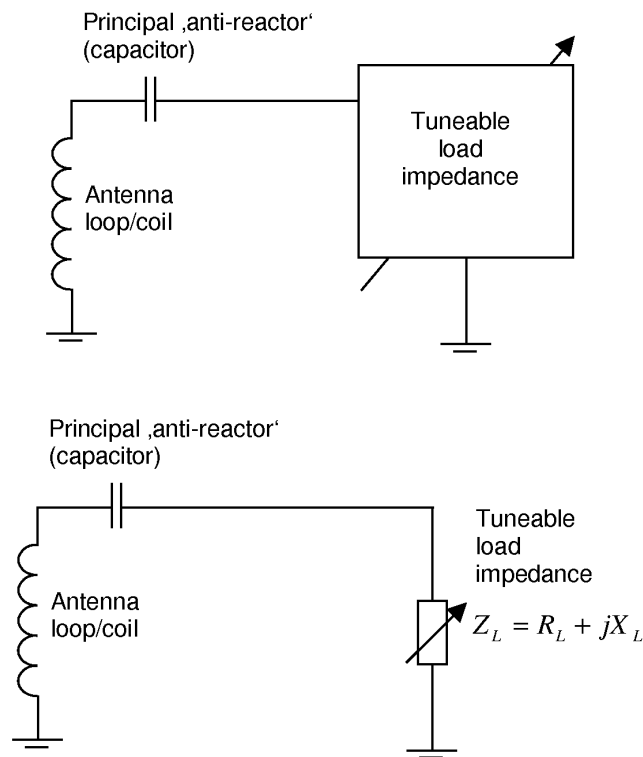


Figure 5-7: Electronic reactance tuning as part of a tuneable load impedance

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

5.3 Integration of receivers into small electronic devices (PEDs)

Integration of receive antennas into small electronic devices is a particular design challenge as there may be

- very limited space available for additional components
- small form factor strongly limiting antenna area (→ low performance)
- dielectric and eddy current losses in PCBs and other components containing lossy dielectric and metallic structure lowering antenna Q-factor
- a potential of electromagnetic interference to certain device functions
- tight cost (BOM) constraints

Ideally, a high Q resonant loop/coil antenna should be separated from the device main body e.g. in a part that can be folded out for the purpose of wireless charging. A device/keyboard cover that can be folded out and that integrates the wireless power antenna as shown in Figure 5-8 a) may be the result of such approach. Such concepts may however be disliked by device manufacturers (OEM) because they will add considerable complexity to the device such as hinges, flexible parts, etc.

As compromise the antenna could be integrated in a part causing lower losses and providing better penetration of magnetic fields because it contains less metallic and/or dielectric structure e.g. in the keyboard part of a mobile phone (see Figure 5-8 a).

At LF eddy currents induced into metallic structures are clearly the predominant loss contributor whilst at HF both eddy currents and dielectric losses may degrade Q-factor.

These material losses must be thoroughly investigated and measured in extensive lab tests, specifically for each device of interest and with respect to the various integration options (e.g. clamp shell type and compact type Figure 5-8 a) and b), respectively), and at LF and HF. Integration losses are considered an important factor to be taken into account in the choice of the frequency (LF or HF).

At LF, ferrite rod antennas are particularly interesting with respect to their integration in small compact devices. Ferrite cores tend to concentrate the magnetic field into the core reducing magnetic field strength in the surrounding thus lowering eddy current losses in the device. Though likely outperformed by air loop/coils in the non-integrated state, Ferrite antennas may perform better when bench marked in the integrated state. These effects have to be thoroughly investigated in extensive lab tests with respect to their integration into 'compact' type or 'clamp shell' type devices as illustrated in Figure 5-8 c) and d), respectively.

Clearly, the use of a ferrite rod antenna would require a magnetic field perpendicular to that of an air coil aiming at maximum induction. Thus orientation either of transmit antenna or device must be changed relative to a system using a device with an integrated air loop receive antenna.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

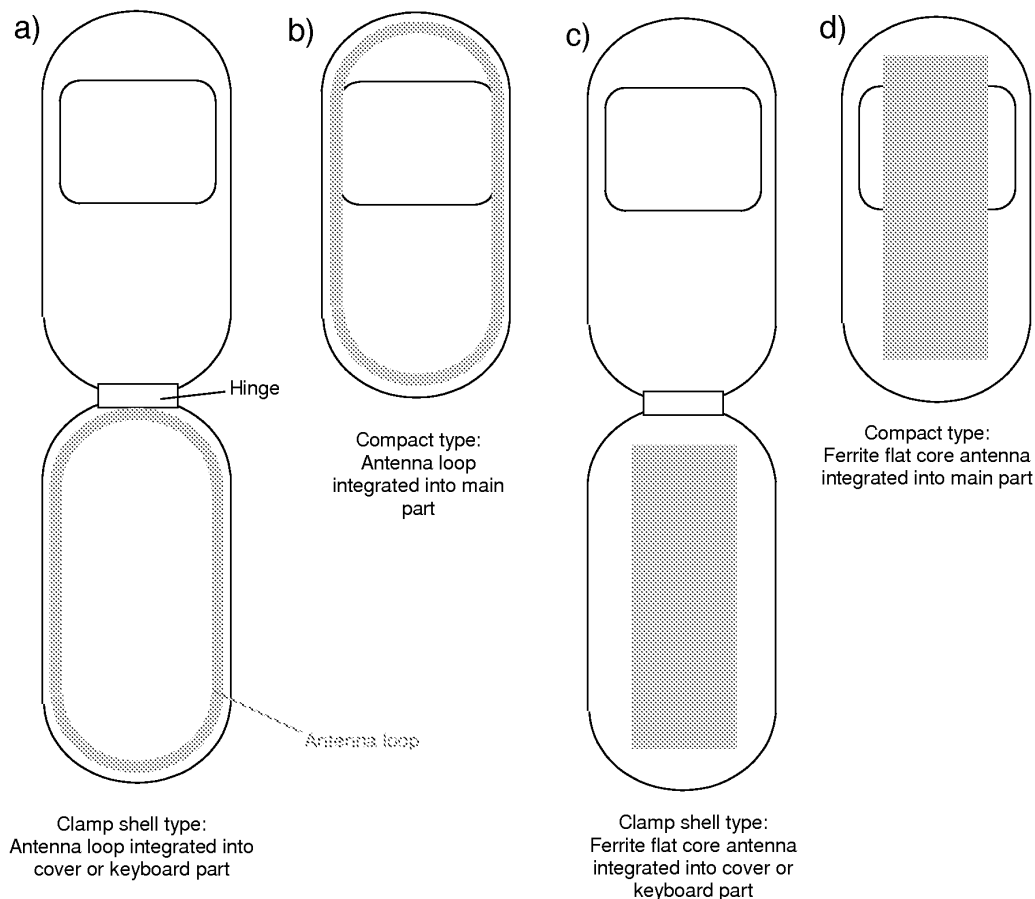


Figure 5-8: Different ways to integrate a receive antenna into a small electronic device (e.g. cellular phone)

5.4 Efficient power conversion

Wireless energy transfer based on magnetic coupled resonance generally involves a number of power conversion stages in both transmitting and receiving subsystem. This can be seen e.g. from the block diagrams of the Wireless Power Bridge as shown in Figure 4-11 and Figure 4-12 for the transmitter and the receiver, respectively.

In order to achieve high end-to-end transfer efficiency, each stage must be optimised, as losses will accumulate across the chain.

Transmit side, particular emphasis must be placed on the power stage driving the transmit antenna. Typically, a half bridge inverter in conjunction with a series antenna tank circuit is used for wireless power transmission at LF. This well known concept is particularly advantageous since this circuit results in a maximum output current at resonance and a current drop in off resonance conditions and generally low harmonic levels.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

In order to obtain high efficiency it requires that the real part of the inverters source impedance is considerably smaller than the equivalent series loss resistance of the antenna tank circuit. Ideally, there is no power dissipation in the transmitters source resistance. All generated energy is either transferred to a receiver or partially dissipated in the transmit antennas loss resistance. The latter can be minimised but not totally eliminated with today's technologies (room temperature superconduction not invented yet).

Power and efficiency control of the transmitter may be performed by either the DC supply voltage of the half bridge inverter or by the duty cycle of the driving waveform, or both.

Receive side, the rectifier and load adaptation are considered the major design challenges. Provided that a rectifier can be built with very low voltage drop and ohmic losses, the rectifier may be inserted directly into the antenna circuit e.g. into a series tank circuit, analogous to the transmitter. Here again, the losses in the rectifier should ideally be insignificant for any loading within required range. Classical rectifiers e.g. Schottky diodes are not suitable for such concepts. So-called synchronous rectifiers based on synchronously switched transistors may be a solution to this problem. Load adaptation and current control (in case of wireless battery charging) may be performed with highly efficient step-down (Buck) or step-up (Boost) converters.

In a multiple receiver scenario, adaptivity over a wide range is required, since receivers must be able to maintain power into load at any coupling factor and in a worst case without assistance of the transmitter (see subsection 5.5.2).

5.5 Load power and system efficiency control

5.5.1 Single receiver

In a single receiver scenario where the coupling factor (distance) between transmit and receive antenna may vary in a wide range, power transfer into the load at receive end must generally be controlled. This will be true in most wireless powering and charging applications. Disregarding overall system efficiency, it would principally be sufficient to control power only in the receive subsystem.

If however overall transfer efficiency is an issue, the system should additionally perform efficiency control. Efficiency control requires the transmit subsystem to additionally perform antenna input power control by adapting its transmit parameters accordingly.

A system that performs both power and efficiency control will hopefully converge to a state where overall transmission efficiency is at a maximum. In this state, receive antenna will be differently loaded than in a system performing receive power control only.

It can theoretically be shown that receive power can be controlled by adapting the antennas load impedance. Load adaptation may require a circuit that is highly adaptive meaning that the receiver must be capable to vary the antenna loading in a wide range.

It can also be theoretically shown that in a system based on coupled resonance, there is no requirement to readjust antenna frequency tuning when the coupling factor between antennas is changing, provided that each antenna is correctly tuned to the operating frequency independent of its loading. Thus the problem of adapting the system to different coupling factors reduces to load adaptation.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

5.5.2 Multiple receivers

The multiple receiver scenario is much more complex since in general there exist different receivers in different coupling conditions also having different power demand. An example of a multiple receiver scenario that may result e.g. in the wireless desktop IT application described in section 4.1 is sketched in Figure 5-9.

In a multiple receiver scenario power and receive antenna loading control is of vital importance. A receiver approaching the transmitter ideally should not negatively affect power transmission to other more distant receivers e.g. by sucking off large amount of power or mismatching the transmitter.

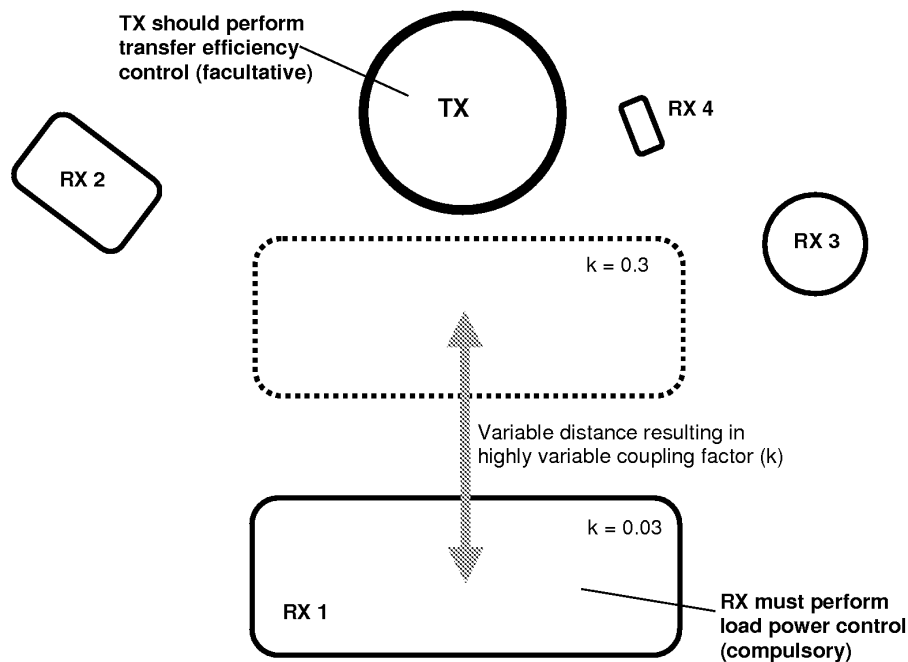


Figure 5-9: Power and transfer efficiency control to compensate variable coupling factor and to share available power among receivers in an equitable manner and according to their demand (Example shows a coplanar arrangement as proposed for the desktop IT application)

A similar problem may result if two receivers are approaching each other and start to mutually couple. Therefore, proper load control in each receiver is compulsory to manage all these different scenarios.

What overall transfer efficiency concerns, there is a fundamental difference between a single and a multiple receiver scenario. In case of a single receiver, efficiency control is straight forward and does not require additional communication between transmitter and receiver, whilst in a multiple receiver scenario transfer efficiency control is much more complex and may also require data exchange (communication) between transmitter and receivers to optimally adjust system parameters. Efficiency control will also be less effective, as the system may need to consider the link with lowest coupling factor, thus not being able to improve efficiency in the

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

more favourable links. In other words: a single distant receiver can degrade the overall transfer efficiency in a multiple receiver scenario.

5.6 Regulatory and EMC issues

5.6.1 Frequency regulatory

The use of frequencies for wireless transmission with a power above a certain uncritical level normally requires a licence and a specific assignment of that frequency for this purpose/service. Frequencies in so-called ISM bands are exempted from such regulation. There exist a number of ISM bands in the frequency range that could principally be used for wireless power applications.

For vicinity coupling systems designed to operate over distances say up to 1 m, frequencies in the VLF, LF, or HF spectrum are of particular interest. Presently there are however only a few ISM bands permitting licence-exempt operation at increased magnetic field strength levels. Some of these bands are allocated below 135 kHz (VLF, LF). Another narrow band exists in the HF spectrum at 13.56 MHz (+/- 3 kHz).

The regulatory norm applicable in these frequency bands defines emission limits e.g. in terms of magnetic field strength measured at a specified distance from the radiation source. The distance specified by ECC for Europe differs from that specified by FCC for US, thus fields strength limits cannot easily be compared.

At the first glance it looks like that LF allows for higher emission levels thus being advantageous over HF. It shall be noticed however that the magnetic field strength resulting at LF is higher than that at HF assuming equivalent systems transferring equal power with equal efficiency over the same distance. In theory the field strength resulting at 135 kHz (LF) is 20 dB higher compared to 13.56 MHz (HF). Present regulations take this fact partially into account but unfortunately not fully. Limits at LF are comparatively more restrictive than those defined for HF. This is another aspect to be taken into consideration for the choice of frequency.

Moreover, comparing ECC and FCC emission limits taking into account proposed factors for distance correction let appear that FCC is generally more restrictive than ECC, though many products used in Europe are also traded and operated in US (e.g. high power RFID readers).

Establishing a very narrow frequency band at LF (e.g. +/- 100 Hz) permitting licence exempt operation at increased levels on a world-wide basis may be thinkable. Such allocation would however require lobbying activity from various stake holder groups of the wireless power and RFID scenery and the proof that wireless power systems would not cause harmful interference to relevant radio services. Similar developments already happened at 13.56 MHz where emission limits were increased by almost 20 dB upon pressure of the RFID lobby. This change request was accepted by regulatory bodies, since RFID readers transmit a strong CW component requiring virtually zero bandwidth.

5.6.2 EMC with non-radio systems

The primary purpose of frequency regulation is to protect radio services from mutual interference. There exist however a number of non-radio systems with limited immunity to electromagnetic radiation such as

- wire bounded communication systems (mainly those using non-properly shielded lines such as powerline, ADSL, VDSL, etc.)
- safety critical systems such as cardiac pacemakers

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

- security critical systems such as credit cards, etc.

These systems are not specifically protected by frequency regulatory norms. Co-existence (EMC) with wireless power systems has to be tested on a case-by-case basis.

The fact that envisaged wireless power systems produce essentially non-modulated radiation fields, is certainly a major advantage in regard to these EMC aspects. The interference potential from modulated or pulsed emissions such as produced by high power RFID, induction cooking, etc. is known to be much higher in general.

5.6.3 Radiation exposure of biological matter

5.6.3.1 General

Beside frequency regulatory norms regulating coexistence of radio systems, radiation exposure limits have additionally been established to protect from adverse biological effects. The biologic limits are set based on scientifically proven thresholds above which adverse health effects may occur. They usually also include a safety margin.

In the frequency range of interest for wireless power applications, radiation is termed non-ionizing radiation (NIR). One relevant association concerned with non-ionizing radiation protection is INIRC that was established in 1992. Their function is to investigate the hazards, which are associated with different forms of NIR, to develop international guidelines on NIR exposure limits and to deal with all aspects of NIR protection. The ICNIRP is a body of independent scientific experts consisting of a main Commission of 14 members, 4 Scientific Standing Committees and a number of consulting experts. They also work closely together with the WHO in developing human exposure limits.

They have produced guidelines for limiting electromagnetic field exposure in order to provide protection against known adverse health effects [ICN 98].

Various scientific studies have been performed world wide. Results of these studies were used to determine thresholds at which the various adverse health effects could occur. The basic restrictions are then determined from these thresholds including varying safety factors.

Basic restrictions and reference levels have been provided by INIRC for two different categories of exposure:

- General public exposure: exposure for the general population whose age and health status may differ from those of workers. Also, the public is, in general, not aware of their exposure to fields and cannot take any precautionary actions (more restrictive levels)
- Occupational exposure: exposure to known fields allowing precautionary measures to be taken if required (less restrictive levels)

5.6.3.2 Coupling mechanism with living matter

The coupling mechanisms through which time-varying fields interact with living matter may be divided into three categories:

- coupling to low-frequency electric fields results in reorientation of the electric dipoles present in the tissue
- coupling to low-frequency magnetic fields results in induced electric fields and circulating electric currents
- absorption of energy from electromagnetic fields results in temperature increase which can be divided into four subcategories:

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

-
- 100 Hz – 20 MHz: energy absorption is most significant in the neck and legs
 - 20 MHz – 300 MHz: high absorption in the whole body
 - 300 MHz – 10 GHz: significant local non-uniform absorption
 - > 10 GHz: energy absorption occurs mainly at the body surface

5.6.3.3 Scientific bases used by INIRC

The following is a description of the scientific bases that were used by INIRC in determining the basic restrictions for different frequency ranges:

- 1 Hz – 100 kHz: restrictions are based on current density to prevent effects on nervous system function
- 100 kHz – 10 MHz: restrictions are based on the Specific Energy Absorption Rate (SAR) to prevent whole-body heat stress and excessive localized tissue heating as well as current density to prevent effects on nervous system function
- 10 MHz – 10 GHz: restrictions are based solely on SAR to prevent whole-body heat stress and excessive localized tissue heating

The basic restrictions are based on acute, instantaneous effects in the central nervous system and therefore the restrictions apply to both short term and long term exposure.

5.6.3.4 Biological effects

A summary of the biological effects for each frequency range is shown below:

Frequencies below 100 kHz:

- Exposure to low frequency fields are associated with membrane stimulation and related effects on the central nervous system leading to nerve and muscle stimulation.
- There is little evidence that magnetic fields have a tumor-promoting effect and the data is insufficient to conclude whether these fields promote the growth of currently present cancerous cells.
- Laboratory studies have shown that there is no established adverse health effects when induced current density is at or below 10 mA/m².

Frequencies above 100 kHz:

- Between 100 kHz and 10 MHz, a transition region occurs from membrane effects to heating effects
- Above 10 MHz the heating effects are dominant
- Temperature rises of more than 1-2°C can have adverse health effects such as heat exhaustion and heat stroke
- A 1 °C body temperature increase can result from approximately 30 minutes exposure to an electromagnetic field producing a whole-body SAR of 4 W/kg
- Pulsed (modulated) radiation tends to produce a higher adverse biological response compared to CW radiation. An example of this is the “microwave hearing” phenomenon where people with normal hearing can perceive pulse-modulated fields with frequencies between 200 MHz – 6.5 GHz

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

5.6.3.5 Summary and conclusion on radiation exposure limits

For health/biological limits, all organisations and regulatory bodies throughout the world agree upon the scientific findings that a whole body SAR of 4 W/kg is the threshold at which adverse health effects can occur. They also agree that for the basic restrictions, a safety factor of 10 should be used, so that the basic restrictions on whole body SAR should not be any higher than 0.4 W/kg for occupational exposure and 0.08 W/kg for general public exposure.

Where the different standards disagree is in regard to the H-field reference levels for human exposure. The IEEE provides the most non-restrictive limits based on a variety of scientific studies. The IEEE limits are generally accepted in north America (as they are also approved by ANSI) as well as NATO. The most restrictive levels are provided by ICNIRP as a large safety factor is taken into consideration for these limits. Japanese proposed limits are somewhere between the IEEE and ICNIRP limits. There is no evidence showing that the limits proposed by the IEEE C95.1 standard would still provide dangerous exposure levels.

In all cases, the human exposure H-field reference levels can be exceeded, as long as a whole-body SAR of 0.08 W/kg is not exceeded.

5.6.3.6 Impact on wireless power applications

What envisaged wireless power applications for vicinity coupling is concerned, magnetic field strength is generally below IEEE/NATO limits. It may however exceed ICNIRP limits at positions close enough to transmit or receive antennas. As magnetic fields in the near field of an antenna increase with 3rd power of distance, there is always a radius where ICNIRP limits may be exceeded, also depending on antenna size, performance, and power/currents.

In contrast to frequency regulatory limits, radiation exposure limits do not specify a distance from the radiation source where field strength has to be compliant. They have to be interpreted as applying to all loci where biological matter may be located, which makes definition of compliance fuzzy.

This problem is however not unique to wireless power but is also an issue of other systems such as RFID systems, induction cooking, induction welding, etc. Such systems require judgement and certification by a competent body.

Concluding, radiation exposure is an issue requiring serious investigation not least because of the increasing phobia of electromagnetic radiation among a majority of people, especially in Europe. It is considered a big challenge and a potential risk of vicinity coupling wireless power mainly in mass market applications.

5.6.3.7 Transmission activity control to reduce radiation exposure

Some people may not like to be continuously exposed to AC magnetic fields e.g. whilst working at their office desk, independently of their actual strength relative to established limits.

Transmission activity control might be a solution to this problem. Devices are only charged during time of absence (e.g. during the night) using a human presence detector (e.g. microwave movement or infrared sensor or both, or other methods). During time of presence of a human being in the proximity or vicinity of the transmit antenna, power is switched-off or reduced to lower levels.

It is assumed that devices provide receive power level indicator to ensure that they are kept in a position/orientation such to receive sufficient power from the transmitter.

This indicator function needs to be preserved also during non-active times or in times of reduced power mode.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

This may be accomplished through the following alternative methods

- periodic very low duty cycle activation of transmitter using soft power ramp-up or ramp-down in order to avoid EMI problems (e.g. 'clicks' in devices having an audio interface such as phones, speaker systems, etc.)
- continuous transmission at reduced power levels but sufficiently high to be detected by the device to control the level indicator

5.6.4 Energy saving measures

5.6.4.1 ENERGY STAR Guidelines

Office equipment (personal computers, monitors, fax machines, scanners, copiers, printers, etc.) accounts for a large proportion of electricity consumption in the tertiary sector. In the context of international commitments, particularly in the area of climate change (notably the Kyoto Protocol), and given its objectives in such areas as sustainable development, the energy-efficiency initiatives take on special significance. The coordinated labelling programme (known as ENERGY STAR) will enable consumers to identify energy-efficient appliances and should therefore result in electricity savings that will help not only to protect the environment but also to ensure the security of energy supply. The programme may also help to encourage the manufacturing and sale of energy-efficient products.

Energy star guidelines have already been implemented and may also affect to a certain degree future market introduction of wireless power products.

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

6 Proximity vs. vicinity coupling systems

In the last years, a number of companies also supported by academia have started research and development activities in the area of wireless power mainly in regard to applications in the consumer market sector. A majority of these initiatives focus on solutions using inductive coupling as the technological basis. Typical solutions are inductive charging pads designed for contactless charging of a single or multiple devices. In all these solutions power is transferred over very short distances say in the range of millimetres or centimetres. Using the terminology of the RFID world, these systems/solutions fall into the category of proximity coupling systems.

Similarly to RFID applications, a proximity coupling solution for wireless powering and charging is not always practical and cannot provide the flexibility/mobility and degree of freedom expected by users. This is the rational behind power transmission over larger distances in the range of decimetres or even metres. Using again RFID terminology, such systems may be associated to the category of vicinity coupling systems.

The price for more range and flexibility/mobility is generally

- higher radiation levels
- higher device integration impact in terms of complexity and costs (BOM)
- lower transferable power
- lower transfer efficiency

In Table 6-1 below, proximity coupling and vicinity coupling is compared with respect to selected aspects that are considered relevant.

**Report D5-1 Wireless power - motivation, generic
system, product ideas, technological challenges and
risks**

	Proximity coupling	Vicinity coupling
Basic solution	Wireless power enabled devices must be positioned on an inductive pad (virtually zero range but contactless)	Wireless power enabled devices can be positioned in proximity or vicinity of a power base (short range)
Basic technology	Classical inductive coupling with high coupling factor and low Q resonance	Magnetic coupled resonance (inductive coupling with high Q-resonance to compensate for low coupling factor)
Energy efficiency	Higher Close to those of corded solutions possible (60 to 90%)	Lower Depending on position/distance of device (0.5 – 90 %)
Radiation exposure/ EMC issues	Lower - No particular problems expected for smart charging pads that can automatically detect loads and control power accordingly. - Less constraints on transferable power	Higher - Tight constraints for transferable power and range by radiation exposure limits - Potential of interference of other systems susceptible to strong magnetic fields (not exhaustively tested yet) - May require more public convincing - May require special means to control field strength in human presence to get market acceptance

Report D5-1 Wireless power - motivation, generic system, product ideas, technological challenges and risks

Frequency regulatory & standardisation efforts	Lower • Can be designed more easily to meet existing regulations & standards • Potential to be supported by a broad stakeholder group thus becoming a main stream standard	Higher • May require new regulations and standards specific to wireless power • May require some lobbying efforts to get approval of frequency authorities • May require standardised wireless power interface and frequency to achieve device compatibility • Standardisation efforts might be torpedoed by stakeholders of proximity systems
Implementation costs (BOM impact)	Lower • Very simple RX solutions possible • Lower Q-factor in base and RX • Tuning in RX not compulsory	Higher • High Q-factor required leading to higher voltages/ currents (physically larger components needed) • Precise tuning in base and RX compulsory • Wide-range adaptability in RX required
Impact on device design	Lower • Solutions with very low impact on device size/form factor and internal circuitry possible	Higher • Larger/more bulky antennas & likely more complex electronics required • More design constraints to preserve high Q-factor
Device positioning degree of freedom	Lower • No solution e.g. for wireless desktop applications	Higher • Attractive solutions e.g. for wireless desktop applications (e.g. for charging keyboard, mouse)
Multiple device powering/charging	Limited depending on size of pad and available transmit power	Less limited depending on available transmit power

**Report D5-1 Wireless power - motivation, generic
system, product ideas, technological challenges and
risks**

Potential risks	• Risk of “me too” products • Commercial availability of products too late • Risk of patent infringements	• Considerably more R&D effort needed than expected • Risk to fail due to above CONs • Commercial availability of products too late • May not be economical for high volume consumer markets • May end up in niche market applications
Competition	Higher several companies announce to be able to show up first products in 2009 or 2010 Potential developments by • Fulton Innovation (eCoupled) • Splashpower • Edison Electric • WiPower • Epson/Murata/Hanrim Postech	Lower so far only few commercial initiatives known in this area • Powercast but using RF radiative principles instead of resonant inductive coupling

Table 6-1: Comparison of proximity vs. vicinity coupling systems

Under the Paperwork Reduction Act of 1995, no persons are required to respond to a collection of information unless it contains a valid OMB control number.

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	NigelPower-PP21Packaging
		Application Number	
Title of Invention	Packagin of a Wireless Power device		
The application data sheet is part of the provisional or nonprovisional application for which it is being submitted. The following form contains the bibliographic data arranged in a format specified by the United States Patent and Trademark Office as outlined in 37 CFR 1.76. This document may be completed electronically and submitted to the Office in electronic format using the Electronic Filing System (EFS) or the document may be printed and included in a paper filed application.			

Secrecy Order 37 CFR 5.2

☐ Portions or all of the application associated with this Application Data Sheet may fall under a Secrecy Order pursuant to 37 CFR 5.2 (Paper filers only. Applications that fall under Secrecy Order may not be filed electronically.)

Applicant Information:

Applicant 1					Remove
Applicant Authority		☒ Inventor		☐ Legal Representative under 35 U.S.C. 117	☐ Party of Interest under 35 U.S.C. 118
Prefix	Given Name	Middle Name	Family Name	Suffix	
	Nigel		Cook		
Residence Information (Select One) ☒ US Residency ☐ Non US Residency ☐ Active US Military Service					
City	El Cajon	State/Province	Ca	Country of Residence i	US
Citizenship under 37 CFR 1.41(b) i		GB			
Mailing Address of Applicant:					
Address 1		1739 Vakas Drive			
Address 2					
City	El Cajon	State/Province	Ca		
Postal Code	92019	Countryi	US		
Applicant 2					Remove
Applicant Authority		☒ Inventor		☐ Legal Representative under 35 U.S.C. 117	☐ Party of Interest under 35 U.S.C. 118
Prefix	Given Name	Middle Name	Family Name	Suffix	
	Hanspeter		Widmer		
Residence Information (Select One) ☐ US Residency ☒ Non US Residency ☐ Active US Military Service					
City	Solothurn	Country Of Residence i	CH		
Citizenship under 37 CFR 1.41(b) i		CH			
Mailing Address of Applicant:					
Address 1		Jasmineweg 1, CH5512			
Address 2					
City	Wohlenschwill	State/Province			
Postal Code		Countryi	CH		
Applicant 3					Remove
Applicant Authority		☒ Inventor		☐ Legal Representative under 35 U.S.C. 117	☐ Party of Interest under 35 U.S.C. 118
Prefix	Given Name	Middle Name	Family Name	Suffix	
	Lukas		Sieber		
Residence Information (Select One) ☐ US Residency ☒ Non US Residency ☐ Active US Military Service					
City	Fribourg	Country Of Residence i	CH		

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	NigelPower-PP21Packaging
		Application Number	
Title of Invention	Packagin of a Wireless Power device		

Citizenship under 37 CFR 1.41(b) i		CH	
Mailing Address of Applicant:			
Address 1		Tannevaldstrasse 64,	
Address 2		CH4600	
City	Fribourg	State/Province	
Postal Code		Countryi	CH
All Inventors Must Be Listed - Additional Inventor Information blocks may be generated within this form by selecting the Add button. Add			

Correspondence Information:

Enter either Customer Number or complete the Correspondence Information section below. For further information see 37 CFR 1.33(a).			
☐ An Address is being provided for the correspondence Information of this application.			
Customer Number	74162		
Email Address	harris@schiplaw.com		Add Email Remove Email

Application Information:

Title of the Invention	Packagin of a Wireless Power device		
Attorney Docket Number	NigelPower-PP21Packaging	Small Entity Status Claimed ☒	
Application Type	Provisional		
Subject Matter	Utility		
Suggested Class (if any)		Sub Class (if any)	
Suggested Technology Center (if any)			
Total Number of Drawing Sheets (if any)		Suggested Figure for Publication (if any)	

Publication Information:

☐ Request Early Publication (Fee required at time of Request 37 CFR 1.219)
☐ Request Not to Publish. I hereby request that the attached application not be published under 35 U.S. C. 122(b) and certify that the invention disclosed in the attached application has not and will not be the subject of an application filed in another country, or under a multilateral international agreement, that requires publication at eighteen months after filing.

Representative Information:

Representative information should be provided for all practitioners having a power of attorney in the application. Providing this information in the Application Data Sheet does not constitute a power of attorney in the application (see 37 CFR 1.32). Enter either Customer Number or complete the Representative Name section below. If both sections are completed the Customer Number will be used for the Representative Information during processing.			
Please Select One:	☒ Customer Number	☐ US Patent Practitioner	☐ Limited Recognition (37 CFR 11.9)

Application Data Sheet 37 CFR 1.76		Attorney Docket Number	NigelPower-PP21Packaging
		Application Number	
Title of Invention	Packagin of a Wireless Power device		
Customer Number	74162		

Domestic Benefit/National Stage Information:

This section allows for the applicant to either claim benefit under 35 U.S.C. 119(e), 120, 121, or 365(c) or indicate National Stage entry from a PCT application. Providing this information in the application data sheet constitutes the specific reference required by 35 U.S.C. 119(e) or 120, and 37 CFR 1.78(a)(2) or CFR 1.78(a)(4), and need not otherwise be made part of the specification.			
Prior Application Status		Remove	
Application Number	Continuity Type	Prior Application Number	Filing Date (YYYY-MM-DD)
Additional Domestic Benefit/National Stage Data may be generated within this form by selecting the Add button.			Add

Foreign Priority Information:

This section allows for the applicant to claim benefit of foreign priority and to identify any prior foreign application for which priority is not claimed. Providing this information in the application data sheet constitutes the claim for priority as required by 35 U.S.C. 119(b) and 37 CFR 1.55(a).			
			Remove
Application Number	Country ⁱ	Parent Filing Date (YYYY-MM-DD)	Priority Claimed
			☒ Yes ☐ No
Additional Foreign Priority Data may be generated within this form by selecting the Add button.			Add

Assignee Information:

Providing this information in the application data sheet does not substitute for compliance with any requirement of part 3 of Title 37 of the CFR to have an assignment recorded in the Office.			
Assignee 1			Remove
If the Assignee is an Organization check here. ☒			
Organization Name	Nigelpower, LLC		
Mailing Address Information:			
Address 1	11512 El Camino Real, Suite 100		
Address 2			
City	San Diego	State/Province	Ca
Country ⁱ	US	Postal Code	92130
Phone Number		Fax Number	
Email Address			
Additional Assignee Data may be generated within this form by selecting the Add button.			Add

Signature:

A signature of the applicant or representative is required in accordance with 37 CFR 1.33 and 10.18. Please see 37 CFR 1.4(d) for the form of the signature.
--

Application Data Sheet 37 CFR 1.76		Attorney Docket Number		NigelPower-PP21Packaging	
		Application Number			
Title of Invention		Packagin of a Wireless Power device			
Signature		/Scott C Harris/		Date (YYYY-MM-DD) 2008-03-05	
First Name	Scott	Last Name	Harris	Registration Number	32030

This collection of information is required by 37 CFR 1.76. The information is required to obtain or retain a benefit by the public which is to file (and by the USPTO to process) an application. Confidentiality is governed by 35 U.S.C. 122 and 37 CFR 1.14. This collection is estimated to take 23 minutes to complete, including gathering, preparing, and submitting the completed application data sheet form to the USPTO. Time will vary depending upon the individual case. Any comments on the amount of time you require to complete this form and/or suggestions for reducing this burden, should be sent to the Chief Information Officer, U.S. Patent and Trademark Office, U.S. Department of Commerce, P.O. Box 1450, Alexandria, VA 22313-1450. DO NOT SEND FEES OR COMPLETED FORMS TO THIS ADDRESS. **SEND TO: Commissioner for Patents, P.O. Box 1450, Alexandria, VA 22313-1450.**

Privacy Act Statement

The Privacy Act of 1974 (P.L. 93-579) requires that you be given certain information in connection with your submission of the attached form related to a patent application or patent. Accordingly, pursuant to the requirements of the Act, please be advised that: (1) the general authority for the collection of this information is 35 U.S.C. 2(b)(2); (2) furnishing of the information solicited is voluntary; and (3) the principal purpose for which the information is used by the U.S. Patent and Trademark Office is to process and/or examine your submission related to a patent application or patent. If you do not furnish the requested information, the U.S. Patent and Trademark Office may not be able to process and/or examine your submission, which may result in termination of proceedings or abandonment of the application or expiration of the patent.

The information provided by you in this form will be subject to the following routine uses:

1. The information on this form will be treated confidentially to the extent allowed under the Freedom of Information Act (5 U.S.C. 552) and the Privacy Act (5 U.S.C. 552a). Records from this system of records may be disclosed to the Department of Justice to determine whether the Freedom of Information Act requires disclosure of these records.
2. A record from this system of records may be disclosed, as a routine use, in the course of presenting evidence to a court, magistrate, or administrative tribunal, including disclosures to opposing counsel in the course of settlement negotiations.
3. A record in this system of records may be disclosed, as a routine use, to a Member of Congress submitting a request involving an individual, to whom the record pertains, when the individual has requested assistance from the Member with respect to the subject matter of the record.
4. A record in this system of records may be disclosed, as a routine use, to a contractor of the Agency having need for the information in order to perform a contract. Recipients of information shall be required to comply with the requirements of the Privacy Act of 1974, as amended, pursuant to 5 U.S.C. 552a(m).
5. A record related to an International Application filed under the Patent Cooperation Treaty in this system of records may be disclosed, as a routine use, to the International Bureau of the World Intellectual Property Organization, pursuant to the Patent Cooperation Treaty.
6. A record in this system of records may be disclosed, as a routine use, to another federal agency for purposes of National Security review (35 U.S.C. 181) and for review pursuant to the Atomic Energy Act (42 U.S.C. 218(c)).
7. A record from this system of records may be disclosed, as a routine use, to the Administrator, General Services, or his/her designee, during an inspection of records conducted by GSA as part of that agency's responsibility to recommend improvements in records management practices and programs, under authority of 44 U.S.C. 2904 and 2906. Such disclosure shall be made in accordance with the GSA regulations governing inspection of records for this purpose, and any other relevant (i.e., GSA or Commerce) directive. Such disclosure shall not be used to make determinations about individuals.
8. A record from this system of records may be disclosed, as a routine use, to the public after either publication of the application pursuant to 35 U.S.C. 122(b) or issuance of a patent pursuant to 35 U.S.C. 151. Further, a record may be disclosed, subject to the limitations of 37 CFR 1.14, as a routine use, to the public if the record was filed in an application which became abandoned or in which the proceedings were terminated and which application is referenced by either a published application, an application open to public inspections or an issued patent.
9. A record from this system of records may be disclosed, as a routine use, to a Federal, State, or local law enforcement agency, if the USPTO becomes aware of a violation or potential violation of law or regulation.

Electronic Patent Application Fee Transmittal				
Application Number:				
Filing Date:				
Title of Invention:		Packaging of a Wireless Power Device		
First Named Inventor/Applicant Name:		Nigel Cook		
Filer:		Scott C. Harris		
Attorney Docket Number:		NigelPower-PP21		
Filed as Small Entity				
Provisional Filing Fees				
Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Basic Filing:				
Provisional Application filing fee	2005	1	105	105
Pages:				
Claims:				
Miscellaneous-Filing:				
Petition:				
Patent-Appeals-and-Interference:				
Post-Allowance-and-Post-Issuance:				
Extension-of-Time:				

Description	Fee Code	Quantity	Amount	Sub-Total in USD(\$)
Miscellaneous:				
Total in USD (\$)				105

Electronic Acknowledgement Receipt

EFS ID:	2956165
Application Number:	61034116
International Application Number:	
Confirmation Number:	4622
Title of Invention:	Packaging of a Wireless Power Device
First Named Inventor/Applicant Name:	Nigel Cook
Customer Number:	74162
Filer:	Scott C. Harris
Filer Authorized By:	
Attorney Docket Number:	NigelPower-PP21
Receipt Date:	05-MAR-2008
Filing Date:	
Time Stamp:	20:11:12
Application Type:	Provisional

Payment information:

Submitted with Payment	yes
Payment Type	Deposit Account
Payment was successfully received in RAM	\$ 105
RAM confirmation Number	4022
Deposit Account	504376
Authorized User	

File Listing:

Document Number	Document Description	File Name	File Size(Bytes) /Message Digest	Multi Part /.zip	Pages (if appl.)
-----------------	----------------------	-----------	----------------------------------	------------------	------------------

1	Specification	pp21provisional.pdf	801135 526a4cd2b79e13beb172ed8bbc9a4cfe098bddbb	no	55
Warnings:					
Information:					
2	Application Data Sheet	ADSigned.pdf	1057824 cf7138fcc4591ceaeb59e56a93ca8b52a77b847b	no	5
Warnings:					
Information:					
3	Fee Worksheet (PTO-06)	fee-info.pdf	8098 5a24df266421f403b20a908a080c864f273459fa	no	2
Warnings:					
Information:					
Total Files Size (in bytes):			1867057		
This Acknowledgement Receipt evidences receipt on the noted date by the USPTO of the indicated documents, characterized by the applicant, and including page counts, where applicable. It serves as evidence of receipt similar to a Post Card, as described in MPEP 503. <u>New Applications Under 35 U.S.C. 111</u> If a new application is being filed and the application includes the necessary components for a filing date (see 37 CFR 1.53(b)-(d) and MPEP 506), a Filing Receipt (37 CFR 1.54) will be issued in due course and the date shown on this Acknowledgement Receipt will establish the filing date of the application. <u>National Stage of an International Application under 35 U.S.C. 371</u> If a timely submission to enter the national stage of an international application is compliant with the conditions of 35 U.S.C. 371 and other applicable requirements a Form PCT/DO/EO/903 indicating acceptance of the application as a national stage submission under 35 U.S.C. 371 will be issued in addition to the Filing Receipt, in due course. <u>New International Application Filed with the USPTO as a Receiving Office</u> If a new international application is being filed and the international application includes the necessary components for an international filing date (see PCT Article 11 and MPEP 1810), a Notification of the International Application Number and of the International Filing Date (Form PCT/RO/105) will be issued in due course, subject to prescriptions concerning national security, and the date shown on this Acknowledgement Receipt will establish the international filing date of the application.					